Proceedings of the American Physical Society

Minutes of the 1951 Autumn Meeting of the New England Section at Trinity College, Hartford, Connecticut, November 3, 1951

THE thirty-seventh meeting of the New England Section of the American Physcial Society was held at Trinity College, Hartford, Connecticut on Saturday, November 3, 1951. Approximately eighty members of the section were in attendance. Luncheon was held in the Hamlin Dining Hall, and the Department of Physics of Trinity College offered tea to the members and guests of the Society after the meeting.

There were two contributed papers, of which the abstracts follow. There were five invited papers, of which this is the list:

Recent Advances in Radiofrequency Astronomy. E. G. Bowen, *Radiophysics Division, Australia.*

Radiation of the hfs Levels from Galactic Hydrogen. H. I. Ewen, *Harvard University.*

Positronium. Martin Deutsch, *M.I.T.*

Physics of the Transistor. W. H. Brattain, *Bell Telephone Laboratories.*

Propagation of Second Sound in Liquid Helium II. M. A. Herlin, *M.I.T.*

The following officers were elected for 1952: Chairman—Nora Mohler, Smith College; Vice-Chairman—F. W. Constant, Trinity College; Secretary-Treasurer—A. G. Hill, M.I.T.; Executive Committee—W. M. Fairbank, Amherst College; D. H. Frisch, M.I.T.

A. G. Hill, *Secretary-Treasurer*
M.I.T., Cambridge 39, Massachusetts

1. The Energy and Volume Changes Attending the Mixing of Nonpolar Liquids. Robert D. Dunlap and Harold F. Crandall, *University of Maine.*—Recent articles have dealt with the irregular solvent power of hydrocarbon liquids for fluorocarbon liquids. A large increase in volume attending the mixing of these liquids places the molecules in the mixture at a higher potential energy than in the pure components. The resulting energy change is much larger than would be expected from the existing theory of regular solutions. When the volume of n_1+n_2 moles of mixture is represented by $V=n_1\bar{v}_1+n_2\bar{v}_2$, the Hildebrand equation for the partial molal energy of mixing becomes

$$\bar{E}_1-E_0=\left(\frac{n_2\bar{v}_2}{n_1\bar{v}_1+n_2\bar{v}_2}\right)^2\bar{v}_1\left[\left(\frac{v_1}{\bar{v}_1{}^2}\Delta E_1\right)^{\frac{1}{2}}-\left(\frac{v_2}{\bar{v}_2{}^2}\Delta E_2\right)^{\frac{1}{2}}\right]^2-\left(\frac{v_1-\bar{v}_1}{\bar{v}_1}\right)\Delta E_1,$$

in which v_1, v_2, ΔE_1, and ΔE_2 are the molal volumes and energies of vaporization of the pure components and $\bar{v}_1$ and $\bar{v}_2$ are the partial molal volumes. It is possible to represent the volume of n_1+n_2 moles of mixture by the equation $V=(v_1-v_2+b)\times n_1-bn_1{}^2+v_2$. The parameter b may be obtained for various fluorocarbon-hydrocarbon systems by assuming random mixing, coiled molecules and taking the distance between the centers of hydrogen-fluorine atoms on adjacent molecules to be the same in the different systems. The systems considered are: $n-C_5F_{12}-n-C_5H_{12}$, $n-C_7F_{16}-n-C_7H_{16}$, and $n-C_7F_{16}-\text{iso}-C_8H_{18}$. The apparent anomalous solubility of these systems may be explained by considering the volume changes attending their mixing.

2. Rotated Piezoelectric, Elastic, and Dielectric Constants of Quartz. Karl S. Van Dyke and Elva Sterns Creeger, *Wesleyan University.**—Based on accepted values of the elastic, dielectric, and piezoelectric constants of quartz, matrices of these constants have been computed for a complete cycle of rotations of the X'- and Z'-reference axes within the planes of both AT- and BT-cut plates. The matrices will appear in the Sixth Quarterly Report of this laboratory on Piezoelectric Crystal Studies to the Signal Corps dated November 30, 1951. They will also be incorporated in a new edition of *A Manual of Piezoelectric Data* by the senior author to appear as a supplementary volume to the Seventh report, February 29, 1952.

* This work was supported by contract with the U. S. Signal Corps.

Proceedings of the American Physical Society

Minutes of the 1952 Annual Meeting Held at New York City, January 31, February 1–2, 1952

(*Bulletin of the American Physical Society*, Volume 27, no. 1)

THE 1952 Annual Meeting of the American Physical Society, being the 311th meeting altogether, was held on January 31st and February 1st and 2nd in the buildings of Columbia University in New York City. In respect of attendance this was apparently the largest meeting ever, the registration reaching the unprecedented figure of 2215. In respect of the number of contributed papers it was close to the ceiling of recent years, a little short of 300. One might suspect that this is a permanent ceiling for the Annual Meeting; but any such inference is rendered very dubious by the fact that the number of ten-minute papers in electron-physics and solid-state physics has been and is declining while the number of nuclear papers is mounting, and the decline of the former cannot go much farther because the number cannot become negative. (Among the invited papers, nuclear physics did not predominate.) This drifting of non-nuclear physics away from our Annual Meeting has its deplorable aspects, but had it not occurred one may well doubt whether even Columbia University and our extremely able and self-sacrificing Local Committee—headed as usual by W. W. Havens, Jr., with A. M. Sachs and L. Lederman—could have continued to bear the burden.

The features which make this meeting "Annual" by definition are two prescribed by our Constitution and one which is based on tradition. The traditional feature is a joint session with the American Association of Physics Teachers, composed of their Richtmyer Lecture (this year delivered by Enrico Fermi), of their presentation of the Oersted Medal (this year received by A. A. Knowlton), and of our constitutionally required Retiring Presidential Address (this made by C. C. Lauritsen). This annual three-headed feature provides an afternoon of good talk for which our largest theater is none too roomy and the time is none too ample. The other distinctive feature of the Annual Meeting is furnished by the Business Meeting of the Society, the reports which are brought before it, and the actions which it takes. Before going on to these, I chronicle that the diners at the banquet in the Hotel New Yorker on Friday evening—also a joint function of our Society and of the Association—were addressed by O. E. Buckley speaking under the title "Observations and Experiences of a Neophyte in Washington" and R. E. Peierls speaking of physicists in Great Britain. As always, the number of people at the banquet was mute but puissant evidence of the power of the counter-attractions of New York City on a winter evening.

Now we turn to the Business Meeting of the Society, held on Friday morning and slimly attended.

Its first business was to hearken to the report of the Tellers of Election (S. K. Allison, A. W. Lawson, J. R. Platt, and H. R. Voorhees). This confirmed that the following Fellows had been elected to office in the Society for terms commencing at the end of this Annual Meeting: J. H. Van Vleck as President, Enrico Fermi as Vice-President, K. K. Darrow as Secretary, G. B. Pegram as Treasurer (all these for one-year terms); R. B. Brode and W. V. Houston as Councilors for four-year terms; W. P. Allis, F. G. Brickwedde, W. B. Fretter, Conyers Herring, H. W. Leverenz, and Arnold Nordsieck for three-year terms as Members of the Board of Editors with special allocation to *The Physical Review;* S. K. Allison and N. F. Ramsey for three-year terms as members of that Board with special allocation to *Reviews of Modern Physics*.

The main business laid before the meeting was that of taking heed of the financial situation and providing for the financial future of the Society. The financial status as of that date of February 1, 1952, was indeed cheerless and the outlook sinister; the Treasurer reported that the surplus of the Society had wasted away to such an extent that within a few months the Society might be literally unable to pay its bills. This was the result of the almost explosive expansion of *The Physical Review;* our surplus was accumulated during the war years when there was little to publish, was depleted during the subsequent years when there was much to publish, and practically vanished at the end of 1951 after the *Review* had suddenly swollen from 4000 pages annually to nearly 5000!

Two problems faced the Council at its meeting of January 30, the long-range problem of forestalling the recurrence of such a situation and the short-range problem of bridging the gap until the inflow of 1953 dues. The Council attacked the long-range problem by voting to recommend to the Society at its Business Meeting the adoption of an Amendment to Article I Section 1 of the By-Laws. Hitherto this section has prescribed the rates of annual dues; in its latest form it prescribed $14 as the annual dues of Members and $20 as those of Fellows. The new version reads: "The Council shall be empowered to fix the annual dues of Members at any figure not to exceed twenty dollars, and the annual dues of Fellows at any figure not to exceed thirty dollars, these dues to be payable on January first." The Society at its Business Meeting adopted this alteration as an Amendment to the By-Laws. It will be for the Council at its Washington meeting to decide where the new level of dues shall be set for 1953.

Other contributions toward the solving of the long-range problem were made by the Council in raising the (nonmandatory) page charge for articles in *The Physical Review* from $8 to $15 per page in raising the corresponding charge for a "Letter to the Editor" from $10 to $15, in raising from $25 to $30 the subscription rate which nonmembers of the Society must pay for *The Physical Review;* and in imposing a nonmandatory registration fee of one dollar at the impending Washington meeting and at subsequent meetings. The effect of these upon the short-range problem is very slight; but since the meeting ended, this problem has been alleviated by a generous grant from the National Science Foundation, which is available to assist in defraying the deficits which *Physical Review* will have incurred and will yet incur in 1952 and 1953. A fuller description of this grant may be given in a later issue of these Minutes.

The Council set up the 1952 Nominating Committee to provide nominations for terms of office beginning in 1953: its members are C. C. Lauritsen (*Chairman*), S. A. Goudsmit, P. Kusch, R. S. Mulliken, E. M. Piore, C. G. Shull, J. A. Van Allen, V. F. Weisskopf, and J. H. Williams.

The Metropolitan Section of the Society was dissolved at the request of its officers, the sad experience of some twenty years having shown that most of the members of our Society who reside in the Metropolitan area do not attend its meetings however skilfully and attractively these are organized.

The Council elected one candidate to Fellowship and 213 to Membership; their names are appended.

Elected to Fellowship: Carl Wagner.

Elected to Membership: Lawrence K. Akers, James W. Albrecht, William A. Allen, Charles G. Amato, Weston A. Anderson, Charles M. Apt, William F. Arendale, William H. Arnold, Jr., Philip M. Aronson, Kenneth R. Atkins, Walter W. Atkins, Delbert S. Barth, Eugen Baumgartner, John E. Bigelow, Douglas S. Billington, Charles A. Bittmann, Gerhard A. Blass, Thomas H. Blewitt, Eugene I. Blount, Fritz E. Borgnis, Bennett Bovarnick, Mark M. Bowman, Jr., Bob M. Brown, Fred P. Burus, Kenneth J. Button, Cleo C. Byers, Addison D. Campbell, Robert F. Carpenter, Paul E. Carroll, Chang Cheng-Hsiu, Hung-Chi Chang, Syama D. Chatterjee, Francis F. Chen, Walter G. Chesnut, Curtis G. Chezem, Marion E. Cieslicki, Solomon I. Ciolkowski, Ezio Clementel, John V. Crable, Horace D. Crockford, George T. Croft, Thomas L. Cullen, Jackie W. Culvahouse, David W. Curtis, Basil D. Darwent, Alfons J. Daverio, Handel Davies, Marguerite I. Davis, William R. Davis, Michel A. Degallier, Donald W. Denniston, Jr., Bernard G. d'Espagnat, Richard N. Dexter, Donald G. Doran, Rene C. Dugas, Arthur W. Ehler, Andrew H. Eschenfelder, David C. Evans, Marjorie W. Evans, Heinz Ewald, William W. Farley, 3rd, Amiel Feinstein, Paul J. Flory, Robert S. Flum, Anthony H. Foderaro, Alan B. Fowler, Elbert M. Fox, Raymond Friedman, Lawrence W. Friedrich, S.J., Fritz E. Froehlich, Yoshio Fukioka, Thomas E. Gilmer, Jr., Thomas N. K. Godfrey, Philip Goldstein, Lionel Goodman, Edwin K. Gora, Alvin S. Gordon, Selma W. Greenwald, Joseph W. Griffith, Samuel B. Gunst, Paul J. Haigh, Neil E. Handel, Francis B. Harrison, John A. Harvey, Shigoaki Hatano, Albert R. Hibbs, Peter Hofmann, Harry D. Holmgren, Richard B. Holtzman, John H. Hubbell, Isao Imai, Akira Isihara, John Jagger, David Jaffe, G. Sargent Janes, Russell D. Johnson, Jr., Robert W. Johnston, Willard C. Jordan, Marvin I. Kalkstein, Osamu Kawaguchi, Jerome P. Keuper, Joseph A. Kies, William E. Kinney, Jean I. King, Ralph Klein, Jere D. Knight, Yoriko Komiya, Cecilia M. Kotin, Eugene H. Koziana, Paul Kruger, Behram Kursunoglu, John E. Lancaster, Robert D. Laughlin, Harlan W. Lefevre, Howard B. Levine, Harry Letaw, Jr., Wei-chuwan Lin, Stephen J. Lukasik, Jr., Marvin L. Luther, Irving L. Mador, Joseph A. Mangiapane, Louis Marick, Hans M. Mark, Clyde L. McClelland, Bruce R. McGarvey, Austin D. McGuire, Carman C. McMullen, Lawrence R. Megill, Donald A. Melnick, Ralph I. Mendenhall, James W. Meyer, George H. Minton, Robert C. Mitchell, Ralph Monaghan, Fulvio R. Monticelli, Richard T. Mooney, Jimmy J. Moore, Donald R. Morey, Stanley R. Morrison, Steven A. Moszkowski, Georges Mourier, John E. Mulhern, Jr., Seitaro Nakamura, V. Alexander Nedzel, Mark S. Nelkin, William A. Newcomb, Gerard J. Nijgh, John B. Nims, Jr., Lee C. Northcliffe, Jr., Richard M. Noyes, Syuzo Ogawa, Carl C. Old, Howard R. Padgitt, Cornelius A. Papp, Eugene N. Parker, William W. Parkinson, Jr., Alfred T. Peaslee, Jr., Frank M. Pelton, Marguerite Perey, Edward L. Peterson, Jr., Russell E. Peterson, Selmer W. Peterson, Elzie Louis Powell, Abbott Pozefsky, Louis A. Rayburn, Theo T. Reboul, John F. Reed, Renato Ricamo, Michael S. Ridout, William A. Robba, Glen P. Robinson, Lawrence G. Rubin, Rudolf Ruetschi, Samuel M. Sanders, Jr., Edward R. Sanford, Donald L. Schaefer, John P. Schiffer, Mark Schindler, Alvin G. Schulz, Jr., William D. Schulz, Felix Schweizer, Louis Segal, Sidney M. Selis, David W. Seymour, Robert C. Shutt, Leonard S. Singer, Charles C. Snow, John Spanos, John A. Spiers, Marilyn J. Stafne, Robert V. Steele, Neil R. Steenberg, Charles C. Sterett, James E. Stewart, Melbourne G. Stewart, Charles H. Sutcliffe, Benjamin E. Tabler, Warren E. Taylor, John H. Tolan, William J. Veigele, Seymour H. Vosko, Rayjor W. H. Webeler, Frederic E. Wells, George R. White, Harrison C. White, Homer C. Wilkins, Michael K. Wilkinson, John C. Williams, Marvin A. Williamson, Jr., Arthur W. Winston, Gordon K. Woodgate, Truman O. Woodruff, and Michael Yamin.

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

Errata Pertaining to Papers F2, F10, G13, H5, J14, M6, O2, P11, and ZC7

F2, by W. F. G. Swann and D. W. Seymour. In line 3, begin should read being. In line 8, observer should read absorber.

F10, by Martin Annis, Herbert S. Bridge, and Stanislaw Olbert. In line 8, $p\beta\alpha R^{\alpha}$ should read $p\beta=f(M)R^{\alpha}$.

G13, by D. W. Seymour and W. F. G. Swann. A footnote should be added reading: Assisted by the joint program of the ONR and AEC.

H5, by W. E. Kreger, R. O. Kerman, and W. K. Jentschke. In the next to the last line, a $P_{\frac{3}{2}}$-wave phase-shift of 180° 47′ should read a $P_{\frac{3}{2}}$-wave phase-shift of 108° 47′.

J14, by T. R. McGuire, Louis N. Howard, and J. Samuel Smart. In the by-line, the same of W. G. Schindler should be omitted.

M6, by Walter F. Dudziak. In lines 16 and 17, the sentence, The σ^- peak occurs at $T_\pi<25$ Mev while the σ^+ peak occurs at $T_\pi>70$ Mev, should read, The σ^- peak occurs at $T_\pi(52<T_\pi<88$ Mev), while the σ^+ peak occurs at $T_\pi'(70<T_\pi'<113$ Mev).

O2, by Ruth F. Schwarz. In line 9, since for $\rho'>\rho$, the$\cdots$, should read, since for $\rho'\neq\rho$, the$\cdots$.

P11, by Edwin A. Crosbie. The first sentence should read: Christian and Noyes[1] have shown that the 32- and 340-Mev *P-P* scattering data are consistent with the scattering to be expected from the usual singlet square well and a triplet tensor interaction of the form ± 18 Mev exp $(-r/R)\times(r/R)^{-2}$, $R=1.6\times10^{-13}$ cm.

ZC7, by M. W. Johns, C. D. Cox, and C. C. McMullen. In line 8, the word uniquely should be deleted. In line 10, (86 percent) and (14 percent) should read (96.5 percent) and (3.5 percent). In line 11, 66° should read 0°.

PROGRAMME

Thursday Morning at 10:00

McMillin

(C. C. Lauritsen presiding)

Invited Papers

A1. Effects of Chemical Combination and of Pressure on the Lifetime of a Nucleus. K. T. Bainbridge, *Brookhaven National Laboratory* (on leave from Harvard University). (40 min.)

A2. Problems of Nuclear Shell Structure. V. F. Weisskopf, *M.I.T.* (45 min.)

A3. The Scattering of Fast Electrons by Nuclei. H. Feshbach, *M.I.T.* (45 min.)

Thursday Morning at 10:00

Pupin 301

(L. J. Rainwater presiding)

Apparatus of Nuclear Physics

B1. Radial Oscillations in the Cyclotron.* P. V. C. Hough, *University of Michigan.*—The excitation and evolution of the radial oscillations of ions in the cyclotron have been studied theoretically and experimentally. If the median plane magnetic field is expanded about $r=r_0$ as $B(r,\theta) = Bo(r_0/r)^n[1+\Sigma_1^\infty h_p(r_0)\cos p\theta]$, it is known[1] that near $n=0$ only the $p=1$ term induces important radial motion and that this motion corresponds simply to a secular shift of the orbit center. The path of the instantaneous orbit center is calculated under the assumptions $(\Delta n/n)$ and $(\Delta h_1/h_1)$ per revolution $\ll 1$. The center moves initially in a direction perpendicular to the axis of h_1 (i.e., the line of excess magnetic field) and then spirals into a circle which corresponds to a precession of the node of the radial oscillation without further change in amplitude. Values of h_1 and n for the Michigan 42″ cyclotron yield a radius for this circle of $\sim 2\frac{1}{2}$ cm, as a result of accidental azimuthal variations of the order 0.1 percent. Asymmetric settling under vacuum of the gasketed iron lid (by a few mils) had previously altered the axis of excess field at each evacuation making a reliable external beam impossible. A systematic shimming procedure is indicated by the theory and discussed in the accompanying abstract.

* Supported in part by the AEC.
[1] Henrich *et al*, Rev. Sci. Instr. 20, 887 (1949); or Hamilton and Lipkin, Rev. Sci. Instr. 22, 783 (1951).

B2. Radial Oscillations in the Cyclotron—Experimental.* W. H. Beach, W. J. Childs, P. V. C. Hough, J. S. King, and W. C. Parkinson, *University of Michigan.*—With the aid of the calculations indicated in the preceding abstract we have found it possible to follow a systematic procedure in shimming to obtain an external beam from a cyclotron. The order of the steps is: (1) central shimming to obtain proper magnetic focusing, (2) adjustment of the median plane, (3) removal of the first harmonic of any azimuthal asymmetries, (4) measurement and elimination of residual radial oscillations, and (5) controlled excitation of an oscillation desirable for extraction of the beam. The adjustment of the median plane is extremely important if the fall-off in the central field region is small. Shims placed around the edge of one of the poles (with care that no first harmonic is introduced) are used for this adjustment. Since azimuthal asymmetries of the order of 0.1 percent introduce serious oscillations, high accuracy in the measurement of the field is required. This may be obtained with the magnetic resonance absorption method. The magnitude of the oscillation, and the center of the orbit may be determined by the use of three internal probes, or by two probes, one of which carries a specially constructed head for determining the angle of the beam at a given radius. A small shim suitably placed may be introduced to excite oscillations in a preferred direction in order that the beam approach the septum at the optimum extraction angle.

* Supported in part by the AEC.

B3. A New Method for Focusing Ion Beams.* F. C. Shoemaker, R. J. Britten,† and B. C. Carlson, *Princeton University.*—An arrangement of small magnetic lenses has been developed for obtaining double focusing of high energy ion beams without the expense of a magnet sufficiently powerful to produce large-angle deflections. The individual lenses have triangular plane-parallel poles and, although the deflection angle is small ($\sim 4°$), have short focal lengths $[f=\rho/(2\tan\frac{1}{2}\theta)]$ where θ ($\sim 90°$) is the angle between the field boundaries. Under these conditions, because of the curvature of the fringing field, their focal lengths in the plane of the field are very nearly equal but opposite in sign to their focal lengths in the plane of the pole faces. However, if two of these astigmats are spaced a distance comparable with their focal lengths with their field directions orthogonal, a point image of a point source may be obtained. If the source distance, the separation of the astigmats, and the desired image distance are specified, the focal lengths required for double focusing can be reliably calculated from the thin lens equation. This arrangement has been applied to the focusing of the 18.5-Mev external proton beam from the Princeton cyclotron. Two 400-pound magnetic lenses, with 400 watts each, focus 25 percent of the internal deflected beam on a $\frac{3}{8}$″ spot 15 feet from the cyclotron.

* Supported by the AEC.
† Now at the Carnegie Institution of Washington.

B4. Monoenergetic Gamma-Rays from the Synchrotron.* J. W. Weil† and B. D. McDaniel, *Cornell University.*—A method of selecting gamma-rays of specific energy from the bremsstrahlung spectrum of the synchrotron has been devised. The magnetic field of the synchrotron analyzes electrons which have undergone thin-target bremsstrahlung emission. Electrons of specified energy are detected by a crystal, the signals from which are then used to gate an external detector so that the detector is only allowed to respond to events which occur in time coincidence with the pulse from the crystal. As an initial test of this method, the internal crystal was counted in coincidence with the Cornell pair spectrometer. The resolution of this arrangement was twenty percent at 170 Mev, the pair spectrometer having a minimum width of ten percent. A fast coincidence apparatus has been constructed to allow the use of moderate intensity beams. A measurement of the velocity of 170-Mev gamma-rays was made as a test of this new apparatus.[1] With this technique, a study of photoproduction of protons from various materials at high energies is now being attempted.

* Supported in part by the ONR.
† AEC Predoctoral Fellow.
[1] D. Luckey and J. W. Weil (to be published).

B5. Čerenkov Radiation Counting.* JOHN MARSHALL, *University of Chicago*.—Scintillation counting is being done in this laboratory with the Čerenkov radiation as a source of light. Since the radiation is dependent in intensity and angle of emission on particle velocity, it is possible with Čerenkov counters to discriminate in various ways among different charged particles of varying velocities. High resolution coincidence work can be done conveniently with these counters because of the extremely short pulses of light. Intensities are rather low so that only quite penetrating particles can be counted conveniently. The design and performance of some of the counters, together with their application to various problems in connection with the Chicago 170-inch synchrocyclotron, will be discussed.

* This work was supported by the joint program of ONR and AEC.

B6. SiO Films.* G. A. SAWYER, W. R. ARNOLD, J. A. PHILLIPS, E. J. STOVALL, JR., AND J. L. TUCK, *Los Alamos Scientific Laboratory*.—Thin self-supporting films of silicon monoxide have been prepared by evaporation into organic (Zapon) film backings which are subsequently removed by ion bombardment or solvents. The films are approximately 100 atoms (8 $\mu g/cm^2$) thick and will withstand 3-mm gas pressure differential while transmitting several μa of 30-kev deuterons at 5-kev energy loss. The measured rms multiple scattering angle in such films at this energy is 7°. Thus beams of low energy charged particles can be introduced into a gas from vacuum with good geometry, small energy loss, and accurately measured intensity. The films are uniform, but at these small thicknesses, the statistics of the energy loss process gives appreciable straggling. We observe a Gaussian distribution of half-width 500 ev about the mean 5-kev energy loss. Al films seem to be equally strong, but have proved unsuitable for precise measurements on account of a growth in stopping power under bombardment, by about 10 percent per hour, presumably by chemical reaction with residual gas.

* Work performed under the auspices of the AEC.

B7. A Diffusion Cloud-Ion Chamber for Detection of Nuclear Interactions.* M. M. BLOCK, W. W. BROWN, AND G. G. SLAUGHTER, *Duke University*.—An ionization chamber has been placed into the sensitive volume of a diffusion cloud chamber consisting of a glass cylinder 16 in. diameter × 9 in. high (filled with argon and amyl alcohol vapor at 1.4 atmospheres), having a sensitive height of ∼4 in. The ion chamber outer electrode, consisting of six $\frac{1}{16}$ in. stainless steel rods arranged in a hexagonal cylindrical array, 3 in. in diameter and 9 in. long, is maintained at a potential of −1200 volts; the central wire, $\frac{1}{16}$ in. stainless steel, is grounded. The amplified ionization pulse can be recorded and fed into delay circuits which cut off the high voltage after electron collection and trigger the flash lamps after track formation. The pulse height can be used to select nuclear events. To date, the chamber has been tested with a polonium alpha source. Successful cloud-ion chambers have been reported[1] using Wilson expansion chambers. However, simplicity and reliability of operation, continuous sensitivity, low cost of fabrication, and large volumes possible in diffusion cloud chambers are distinct advantages.

* This work was supported by the joint program of the ONR and AEC.
[1] Lewis, Brown, Seevers, and Hones, Rev. Sci. Instr. **22**, 259 (1951); Brown, Rau, and Reynolds, Paper E6, Bull. Am. Phys. Soc. **26**, No. 6 (1951) (Chicago meeting).

B8. Gamma-Energy Resolution with Sodium Iodide Scintillation Spectrometer.* C. J. BORKOWSKI AND R. L. CLARK, *Oak Ridge National Laboratory*.—With selected 5819 photomultipliers and 1″×1½″ cylindrical sodium iodide crystals activated with thallium iodide, an 8.0 percent full width at half maximum is obtained for the photoelectric peak from a 670-kilovolt gamma-ray. The peak to valley ratio is 52 to 1. At 42 kilovolts the width is 26 percent. An electron energy loss of 200 electron volts in the crystal releases a single photoelectron from a photocathode whose efficiency is 60 microamperes per lumen. MgO diffuse reflectors were found superior to aluminum foil, especially for the larger crystals; 30 percent more light was obtained. Energy distribution of recoil electrons, photoelectrons, and electron pairs from various energy gamma-rays and for different size crystals up to 3″×3″ cylinders will be shown. Methods for mounting the crystal directly on the photocathode and hermetically sealing the assembly in order to obtain long time surface stability will be given. Variations in sodium iodide crystals and photomultipliers will be discussed.

* This document is based on work performed under contract for the AEC at Oak Ridge National Laboratory.

B9. Mixed NaI−LiI Crystal for a Neutron Spectrometer.* A. W. SCHARDT AND W. BERNSTEIN, *Brookhaven National Laboratory*.—Hofstadter[1] showed that thallium-activated LiI crystals give scintillation pulses with neutrons. This process may be used for rough neutron energy measurements, provided the pulse height is proportional to energy and the resolution is good. The best resolution we obtained with thermal neutrons for a small (2 g) Tl-activated crystal is 14 percent (full width at half maximum). This is to be expected since the pulse height is at most 10 percent of that obtained with NaI − Tl at the same energy. Unfortunately, large crystals give a spread in pulse height caused apparently by nonuniform activation. Clear crystals have been grown from a mixture of 92 percent NaI, 7 percent LiI, and 1 percent TlI by weight. If separated Li^6 were used, this mixture would have the same neutron detection efficiency as natural LiI. The lithium concentration increased by a factor of two from the tip, where the crystal started to grow, to the top part of the melt. A 0.1-g crystal from the tip gave ½ the pulse height of pure NaI and 6.5 percent resolution. Unfortunately, the pulse height is inversely proportional to the lithium concentration and as yet no uniform crystal has been grown. Linearity between gamma-ray and neutron pulses was established. The fluorescent band of the mixed crystal falls between the 4200A and 5400A bands of NaI−Tl and LiI−Tl, respectively.

* This work was performed under the auspices of the AEC.
[1] Hofstadter, McIntyre, Roderick, and West, Jr., Phys. Rev. **82**, 749 (1951).

B10. An Automatic Recording Scintillation Spectrometer for Gamma-Rays. THOMAS D. STRICKLER AND W. G. WADEY, *Yale University*.—The spectrometer to be described makes use of a large NaI/TlI crystal mounted on an RCA 5819 photomultiplier tube and was designed for the high efficiency requirements connected with a study of elastic scattering of gamma-rays. It has proved to have reasonably good resolution and has the added advantage of being completely automatic. This enables it to be used over a considerable period of time for measurement of weak spectra without the constant attention normally required by the single channel pulse height analyzer.

B11. Magnetic Compton Spectrometer. J. W. MOTZ, WILLIAM MILLER, AND H. O. WYCKOFF, *National Bureau of Standards.*—A magnetic spectrometer has been constructed to determine absolute photon intensities and energies over the energy range from approximately 0.5 to 10 Mev with an accuracy of about 5 percent. The instrument measures the momentum distribution of Compton electrons ejected by a photon beam from a thin beryllium foil into a *small* solid angle in the forward direction.[1] The energies of these selected Compton electrons are directly related to the energies of the incident photons. The conversion to absolute photon intensities is based on the integration of the Klein-Nishina differential cross section over the spectrometer acceptance angle. The finite size of the foil requires that the energy and intensity determinations account for (a) the energy loss by the Compton electrons in traversal of the foil and (b) scattering of these electrons in the foil. These effects are evaluated from studies of line shapes obtained with a 10 curie Cs^{137} source for foils of various sizes. The contribution of pair production electrons accepted by the spectrometer at a given energy is found by reversing the field and measuring the corresponding number of positrons.

[1] Similar measurements with radioactive sources have been made by G. D. Latyschev *et al*, J. Phys. (U.S.S.R.) 3, 251 (1940).

B12. Deterioration of Boron Trifluoride Counters Due to Rapid Counting Rates.* R. K. SOBERMAN AND S. A. KORFF, *New York University.*—Twenty-two boron trifluoride counters were run at counting rates ranging from 2,300,000 to 330,000 counts per minute in the proportional region from a radium gamma-source until they all had lost their plateaus. This occurred in from 10^8 to 10^9 counts. The pulse heights decreased to the point where maximum sensitivity of the circuitry failed to record more than a few hundred counts per minute. Although a grass background could be detected on the oscilloscope, raising the voltage will not restore the pulse heights and the counters do not recover after resting up to three months. Samples of the gas and several counters were analyzed on a mass spectrometer. From the appearance potential curves for the BF_3, the analysis of the counters, and from the behavior of the counters, a theory was formulated which would explain the deterioration on the basis of the formation of a negative ion sheath formed when the BF_3 dissociates.

* This work was supported by the ONR.

B13. Photographic Gray Wedge Pulse Height Analysis.* W. BERNSTEIN, R. L. CHASE, M. SLAVIN, J. GARFIELD, AND A. W. SCHARDT, *Brookhaven National Laboratory.*—The gray wedge-oscilloscope method of pulse height analysis described by Maeder[1] has been refined. The pulses from a pulse spectrometer are stretched to give constant vertical deflection across the oscilloscope screen. Photographs of the screen are taken on Kodak 35 mm type IV-F spectroscopic film through a wedge mounted on the oscilloscope face. This film was selected for its good reciprocity, speed, grain size, and color response. The gray wedge is neutral filter glass ground into a wedge which may be stepped or continuous. We have used wedges covering either one or two decades of intensity. Photographic wedges are unsatisfactory because of excessive scattering in the dense portion. The pictures are enlarged on Kodalith paper. The distance along the wedge to the transition is proportional to the logarithm of the counting rate; the distance from the base line gives the energy. The requirements on the oscilloscope are linear deflection amplifier, uniform sweep intensity, no change in focus and intensity with counting rate, blanking of the sweep outside the wedge dimensions, and no shift in the baseline with counting rate. Most commercial oscilloscopes have to be modified. Spectra obtained by this method will be compared to single sliding channel analyzer results.

* This work was performed under the auspices of the AEC.
[1] D. Maeder, Helv. Phys. Acta 20, 139 (1947).

THURSDAY MORNING AT 10:00

Schermerhorn 501

(W. BLEAKNEY presiding)

Invited Papers of the Division of Fluid Dynamics

C1. A Mixing Theory for Dissipative Flows with Increasing Pressure in the Flow Direction. L. CROCCO AND L. LEES, *Princeton University.* (40 min.)

C2. Application of Linearized Characteristic Systems to Supersonic Non-Linear Problems. A. FERRI, *Polytechnic Institute of Brooklyn.* (40 min.)

C3. Flows in the Vicinity of Mach-Number One. G. GUDERLEY, OAR, *Wright-Patterson Air-Force Base.* (40 min.)

Business Meeting of the Division of Fluid Dynamics

THURSDAY MORNING AT 10:00

Havemeyer 309

(J. B. JOHNSON presiding)

Electron Physics: Liquid State

D1. A New Dispenser Type Cathode. JACK MARTIN, *Signal Corps Engineering Laboratories.*—A cathode utilizing the dispenser principle of filtering barium to the outer surface is discussed. Comparisons as regards cathode activation, current density, life and cathode characteristics are indicated in relation to the Philips cathode, and standard nickel sleeved triple carbonate cathodes. It is found that a cathode utilizing a molybdenum sleeve with a triple carbonate coating sprayed under a magnesium oxide surface is simple to activate, gives current densities of 1 to 2 amp per square centimeter under dc conditions at 1000–1050°C brightness, and has a life in the order of several hundred hours, the main limitation being filament burnouts.

D2. Field Dependent Secondary Emission. HAROLD JACOBS AND JOHN FREELY, *Signal Corps Engineering Laboratories.*—Experiments were conducted with magnesium oxide in which high dc fields were applied to the surface at the same time that secondary emission ratios were being observed. It was found under static conditions that the secondary emission ratios increased exponentially with increasing fields. Yields of several hundred to one were observed for two hundred hours and longer. Square wave measurements were also made modulating both the applied field and the bombarding current. The mechanism of this field dependent secondary emission was found to be related to an avalanche effect triggered by bombarding electrons. Several analogies were found between this type of electron emission and phenomenon in a glow discharge.

D3. Basic Principles of an Electron Interferometer. L. MARTON, *National Bureau of Standards.*—The feasibility of an interferometer operated with electrons instead of light is discussed. Such an interferometer preferably should be a wide-beam interferometer, closer to the Mach-Zehnder type than the narrow-beam interferometers of the double-slit type. A wide-beam interferometer requires an efficient beam splitter. The most efficient method of splitting found up to now consists of utilizing Bragg reflection on thin lamellar crystals. The making of such crystals by means of epitaxy is briefly discussed. It is shown that of several possible designs of an interferometer, the one using three parallel crystals seems to have advantages. The usefulness of an electron beam interferometer for various physical measurements such as the determination of very weak field gradients, investigation of the coherence limit of the deBroglie wave, interference spectroscopy and the measurement of band structure of solids, measurement of internal potentials, etc., shall be briefly mentioned.

D4. Limitations of the Electron Interferometer. J. AROL SIMPSON, *National Bureau of Standards.*—Calculations have been carried out to determine the useful design parameters of the electron beam interferometer conceived by L. Marton. It is found that the initial conception of the instrument will need at least eleven degrees of adjustments for the three crystals and two beam-limiting apertures. The main adjustments are: alignment of the crystals to parallel positions, their adjustments with respect to the optical axis of the instrument, and rotation of the crystals to align their crystalline axes. It is found that for all these adjustments the tolerances are well within the limits of present-day experimental techniques and no undue difficulties are expected on this account. The distance of separation of the crystals is prescribed by the fringe spacing, and for reasonable values of the latter the separating distances have been found to be realizable very conveniently in experiment. Further details are added to those contained in the previous abstract on the making of thin lamellar crystals by means of epitaxy.

D5. Electron Mobilities in Liquid and Solid Argon and Liquid Helium.* M. S. MALKIN,† *Yale University.*—The electron mobilities in liquid and solid argon and in liquid helium are measured using a synchroscope technique. The electron mobilities in liquid and solid argon are proportional to the inverse half power of the electric field strength. From comparison of the liquid argon data with data published for gaseous argon, it is shown that liquid argon may be treated as a gas at high pressure. The electron mobility in liquid helium is measured but does not show the same dependence on electric field strength. Attempts were made to observe pulses due to electron collection in solid helium and in liquid helium below the λ-point, but were unsuccessful. A new unexplained effect is noted in the liquid helium work which must be attributed to liquid helium and not to an apparatus defect.

* This work was supported by the ONR.
† Now at Schlumberger Well Surveying Corporation, Ridgefield, Connecticut.

D6. The Diffraction of X-Rays by Liquid Sodium-Potassium Alloys.* R. E. HENDERSON AND N. S. GINGRICH, *University of Missouri.*—Crystal-monochromated x-rays (0.710A) were directed upon samples of sodium-potassium alloys of several different compositions at 105°C, and the diffraction patterns were recorded photographically. Cleaned samples of liquid sodium and potassium were mixed in an evacuated system, sealed off in thin-walled glass tubes, and later analyzed by spectroscopic analysis for composition. The intensity patterns were corrected for absorption, polarization, and incoherent radiation as usual. Five of these patterns were analyzed to determine the electron density distribution, using approximations that are similar to those used for molecular liquids having more than one kind of atom. These distribution curves show the existence of maxima which are generally suggestive of analogous curves for pure sodium or pure potassium but with the positions of the maxima shifting gradually from that for sodium to that for potassium, and with the first peak never tending towards being a discrete peak as in other molecular liquids. Contrary to the conclusion from earlier x-ray diffraction studies,[1] the present work indicates that in liquid sodium-potassium alloys, there are no permanent molecules.

* This work supported by the Research Corporation.
[1] Banerjee, Ind. J. Phys. 3, 399 (1929).

D7. The Self-Diffusion of Liquid Mercury.* R. E. HOFFMAN, *General Electric Research Laboratory.*—Haissinsky and Cottin[1] have recently reported data on the self-diffusion of liquid mercury from measurements on the rate of exchange between radioactive mercury and aqueous solutions of mercurous nitrate. Their results were expressed by the equation $D=1.4(10)^{-5}\exp(-3100/RT)$. These results are abnormal in that the absolute values of the diffusion coefficient are much lower, and the activation energy much higher, than is to be expected from viscosity data. We have used the conventional capillary technique[2] to measure self-diffusion coefficients of liquid mercury, and in the temperature range 0–90°C, our data fit the equation $D=1.26(10)^{-4}\exp(-1150/RT)$. These results are much more compatible with viscosity data. It is concluded, therefore, that diffusion in the mercury is not the rate-controlling step of the exchange process used by Haissinsky and Cottin. Complete details are to be published elsewhere in the near future.

* Work supported by AEC Contract.
[1] M. Haissinsky and M. Cottin, J. phys. radium 11, 611 (1950).
[2] J. S. Anderson and K. Saddington, J. Chem. Soc., S381 (1949).

D8. Production of Electric Turbulences in a Fluid Medium. OLEG YADOFF, *Columbia University.*—The phenomenon of the influence of electric field on electric current in metallic or carbon conductors, described by the author at the last Washington meeting, leads to the observation, under the same experimental conditions, of a new peculiar phenomenon: the production of electric turbulences of a singular nature; they are certainly due to the effect of interaction between the electric field (acting in a closed system concentrically towards the conductor of electric current) and the electro-magnetic field (being part of the electric current). Such turbulences are visible to the eye if colored fumes are introduced into the experimental apparatus. They have the very marked property of decomposing fumes and aerosols. The decomposition is rapid and forceful, but is effected progressively, which facilitates the observation of the formation of the turbulences and their rotation. The change in the direction of the direct current causes the change in the direction of the rotation of the turbulences, which shows their dependence on the electromagnetic field of the direct current. The observations made from the experiments provide evidence that the lines of force forming these turbulences carry through a fluid medium free electrons under atmospheric pressure. These free electrons penetrate into the conductor carrying the electric current. Their existence explains the effect of the chemical decomposition of the fumes and aerosols of every type.

D9. Angular Points in Liquids Versus Temperature. G. ANTONOFF, A. YAKIMAC, A. URMANCZY, AND R. MADRAZO, JR. —Vapor pressures, densities, latent heats, etc. follow a discontinuous path, contrary to classical views. This appears clearly, if density of liquid d_1 less density of vapor d_v, which we call d $(d=d_1-d_v)$, is elevated into power $\frac{1}{3}$. Plotted against temperature $d^{\frac{1}{3}}$ gives a broken line. The angles of intersection correspond accurately to simple integer values of $X=4$, 8, 16, 32, etc., where $X=d_1/d_v$, which according to Antonoff is the association factor.[1] The recent figures for water by N.B.S.[2] show it clearly. Although these values have been "smoothed," the third significant figure has not been affected. One of the authors, H. F. Stimson, wrote: "I have looked over the original papers . . . and failed to find the discrepancies in formulations from our observed values by as much as 1 part in 1000." The effects described are exhibited by the third figure. Therefore our results are beyond all doubts. They are a manifestation of a definite law of nature: Aggregation takes place in stages, according to the law of multiple proportions.

[1] Jerome Alexander, Colloid Chem. **7** (1950).
[2] Natl. Bur. Standards, RP 1229, Washington, D. C.

Post-Deadline Papers, if any

THURSDAY MORNING AT 10:00

Pupin 428

(A. G. SHENSTONE presiding)

Optical Spectroscopy and X-Rays

E1. Spectroscopy from the Point of View of Communication Theory. Part III. Line Shapes. GILBERT W. KING AND A. G. EMSLIE, *Arthur D. Little, Inc.*—The finite aperture of a spectroscope cuts off the Fourier transform of the output signal. Shannon has shown that the amount of information in such a signal, $\Psi(x)$, is limited to amplitudes at intervals $\pi/2$ diffraction widths apart. Intermediate values are given by the interpolation formula $\Sigma\Psi(n\pi/2)\sin(2x+n\pi)/(2x+n\pi)$. Diffraction actually multiplies the transform by a *triangular* filter. This, equivalent to the Fejèr summation process, leads to the more rapidly convergent expression $\Sigma\Phi(n\pi/2)\times[\sin(x+n\pi/2)/(x+n\pi/2)]^2$. The $\Phi(n\pi/2)$ are particular values of the signal without diffraction, seen through a square filter. They can be obtained as correlation sums of Fourier coefficients of the truncated transforms of the separate functions, representing the slits, natural line shape and electrical filter. For a function, such as Beer's law, whose transform is not known, the coefficients can be obtained by correlating with $\sin x/x$. The complicated expression for the contour of a single line at the output should not be fitted by a one-parameter (triangle, Gaussian or Cauchy) formula; nevertheless, it is completely characterized by amplitudes at points $x=n\pi/2$ only. This is borne out experimentally. When there is no distortion by Beer's law or filtering, the shape can be expressed in closed form, involving exponential integrals.

E2. Diffraction by Finite and Infinite Gratings.* SAMUEL N. KARP, *New York University.*—Diffraction of an obliquely incident plane wave by a grating of arbitrary cylinders is investigated mathematically, under the restriction that the spacing is large compared to wavelength and to the dimensions of the obstacle; no restriction is imposed upon the relation of the latter to the wavelength. It is found that the current density induced in each cylinder in the grating can be expressed as a linear combination of the current densities induced upon an *isolated* cylinder by (a) the obliquely incident plane wave, (b) a plane wave progressing to right and to left along the grating. Specialization to the case of circular cylinders small compared to wavelength is also undertaken, and certain resonances are discussed. The excitation of finite or semi-infinite gratings of isotropic scatters [e.g., thin wires] is investigated. In both cases the variation of the amplitude of the cylindrical wave contributed by each scatterer, and also the far field can be obtained simply and without neglect of end effects, when the interaction of scatterers is restricted to that between N nearest neighbors. The validity of this assumption is discussed in terms of the solution for an infinite grating. In the semi-infinite case the restriction may be removed at the expense, however, of extreme complication of the form of the result.

* Research supported in part by the Geophysical Research Division of the Air Force Cambridge Research Center.

E3. Multiple Scattered Reflection from a Striated Surface.* VIC TWERSKY, *New York University.*—The general solution for the multiple scattering of a plane electromagnetic wave by parallel cylinders derived previously is applied to non-specular reflection from a random configuration of semicylindrical bosses on a perfectly conducting plane; correlations higher than the second are ignored. For spacing between neighbors large compared to wavelength and radii, the far field form of the multiply scattered waves are summed explicitly to obtain a solution in closed form for normal incidence, $\alpha=0$, and for $\alpha>60°$. It is found that the effects of multiple scattering are negligible for the component polarized parallel to the bosses for all α, and are significant for the perpendicular component only for large α. The most pronounced departures from single scattering theory occur for the immediate vicinity of grazing incidence. For an infinite distribution and $\alpha\to\pi/2$, each polarization component of the total reflected wave reduces simply to a plane wave differing from the corresponding incident component only by a phase factor of π. This is in agreement with observations for an approximately plane surface of arbitrary surface texture or physical constants.

* Research supported in part by the Geophysical Research Division of the Air Force Cambridge Research Center.

E4. The $3\nu_3$ Bands of CO_2 and CS_2. NORMAN M. GAILAR AND EARLE K. PLYLER, *National Bureau of Standards.*—The $3\nu_3$ band of CO_2 has been studied,[1,2] but in the present investgation the molecular constants and band origin, previously unreported, are determined. A 15,000 line/in. grating spectrometer was employed. A multiple reflection absorption cell with a path length of 6 meters was used. The cell will be described. The presence of atmospheric H_2O displaced some of the rotational lines of this band, and the molecular constants could not be determined with the highest accuracy. The constants determined are in good agreement with the latest values reported.[3] The band origin is 6972.4 cm^{-1}. The spectrum of CS_2 in the region of 2.2μ was examined. Five overlapping bands were observed. The rotational structure of the transition 000→003 was resolved, and band heads of transitions from excited lower states were present. Two band heads involving the S^{34} isotope were observed. Some of the molecular constants for CS_2 have been determined and will be reported.

[1] E. F. Barker and T. Y. Wu, Phys. Rev. **45**, 1 (1934).
[2] L. Goldberg, O. Mohler, A. Pierce, and R. McMath, Phys. Rev. **78**, 74 (1950).
[3] W. S. Benedict, Robert C. Herman, and Shirleigh Silverman, J. Chem. Phys. **19**, 1325 (1951).

E5. Absorption Spectrum of Free NH_2 Radicals. G. Herzberg and D. A. Ramsay, *National Research Council of Canada.*—It is well known that oxy-ammonia flames and discharges through streaming ammonia emit an extremely complicated many-line spectrum in the region 4200–8300A called the α-bands. These bands have been tentatively assigned to the NH_2 radical although other possibilities have also been considered. Since photochemical investigations suggest that NH_2 is formed as the primary step in the photolysis of NH_3, an attempt was made to observe the absorption spectrum of NH_2 in a flash photolysis apparatus. The spectra of the photodecomposition products of NH_3 were photographed within 1 millisecond of the photolysis flash using a 21 ft grating. In the region 5700–6900A many absorption lines were indeed observed which coincide exactly with emission lines from an oxy-ammonia flame. The fact that these α-bands occur in absorption and that they have a structure characteristic of an asymmetric top molecule of small moment of inertia leaves no doubt that they are due to the free NH_2 radical. This conclusion was confirmed by the observation of the α-bands in absorption in the flash photolysis of N_2H_4. In this case the NH band at 3360A also appears strongly in absorption while it does not appear in the NH_3 photolysis.

E6. Emission of the Atmospheric Bands in Discharges and Afterglows in Pure O_2. Lewis M. Branscomb,* *Harvard University.*—The atmospheric bands of O_2 result from a forbidden $^1\Sigma_g^+ - ^3\Sigma_g^-$ magnetic dipole transition with a probability of only 0.14 sec. Conditions are described which permit the strong excitation of these bands in emission in both a direct discharge and the subsequent afterglow in spectroscopically pure oxygen. The spectrum of the afterglow at 1-cm pressure contains only the (0, 0) and (0, 1) atmospheric bands and a weak continuum. Bands up to (4, 4) appear in the direct discharge, along with very strong OI lines. The Schumann-Runge and Herzberg bands are absent, as are bands of O_2^+. Rotational and vibrational "temperatures" measured in both discharge and afterglow show that thermal equilibrium is attained before radiation occurs. This result further justifies the reliance of Meinel[1] and Dufay[2] on the rotational temperature of the (0, 1) band in the night afterglow spectrum.

* Now at the National Bureau of Standards.
[1] A. B. Meinel, Astrophys. J. **112**, 464 (1950).
[2] J. Dufay, Compt. rend. **231**, 1531 (1950) and **232**, 426 (1951).

E7. Forbidden Lines in Spectra of Sb I and As I. M. Hults and S. Mrozowski, *University of Buffalo.*—The excitation of multipole transitions and their hyperfine structure has been already investigated in bismuth vapor.[1] The purpose of this work was to extend the observations to lighter elements. The spectra were excited by high frequency oscillations. The vapor pressure of the metal was varied and several millimeters of helium were added to bring the lines to maximum intensity. Under the optimum conditions the intensity of corresponding line decreases in order Bi I, Sb I, and As I. For antimony two lines $^2P_{\frac{3}{2},\frac{1}{2}} \rightarrow ^4S_{\frac{3}{2}}$ were observed and their structure studied with Fabry-Perot etalons up to 18-mm separation. The line λ5415 shows a partly resolved structure mainly because of the splitting of the upper level $^2P_{\frac{3}{2}}$; the line λ6098 is a wide doublet ($\sim$0.5 cm^{-1}), the components of which split further into two unresolved groups each (isotopes 121 and 123). The splitting of the doublet compared with results of Badami[2] (0.475 cm^{-1}) indicates a total splitting of $\sim$0.05 cm^{-1} for the level $^4S_{\frac{3}{2}}$. For corresponding transitions in arsenic λ5362 was found to be single, and λ5498 was found to be a doublet with a separation of 0.155 cm^{-1}.

[1] S. Mrozowski, Phys. Rev. **69**, 169 (1946).
[2] J. S. Badami, Z. Physik **79**, 224 (1932).

E8. Term Values in Mn III. Howard D. Goldgraber, *University of Pennsylvania.*—The analysis of the spectrum of Mn III by Catalan and Riguelme[1] gives the sextet and the four quartets of the $3d^5$ configuration. These terms were used to calculate the radial integral parameters, which lead to a mean deviation between the observed and calculated terms of 461 cm^{-1}, neglecting configuration interaction. With the correction proportional to $L(L+1)$, first noted by Trees, added as an extra parameter, the mean deviation is reduced to 90 cm^{-1}. Many has estimated the effect of additional parameters on the agreement between theory and experiment by computing the mean error. For the case of three parameters the mean error is 729 cm^{-1}. With the $L(L+1)$ correction added, the mean error is 201 cm^{-1}. The positions of the unknown terms are predicted. The intervals of the terms were calculated from the d^5 spin-orbit matrix which was computed using Racah's methods.

[1] Private communication, courtesy of Dr. Charlotte M. Sitterly.

E9. The Detection of Water-Alcohol Azeotropes through Ultraviolet Spectra.* Gladys A. Anslow and Irene S. White, *Smith College.*—In the spectra of numerous alcohols in isooctane recently reported,[1] appear several absorptions in the longer wavelength region, the strongest of which originate in OH...O and OH^+...O hydrogen bridges, and certain weaker absorptions less certainly in CH...O associations[2] possibly between the solvents and the alcohols. To examine the effect of water-alcohol azeotropes the normal alcohols have been redistilled over silica-gel in a Podbielniak column with helical-glass packing, and successive samples of the first and second distillates examined with the Beckman ultraviolet spectrophotometer. The presence of these azeotropes in the earlier samples of the first distillate shifted the OH^+...O absorptions to lower frequencies than those of the final dry samples, the latter being identical with the onsets reported.[1] In the first samples of methyl and ethyl alcohols a variety of weak onsets appear. Calculations indicate their origins in azeotropes with various numbers of water molecules. In the later samples fewer onsets appear, the strongest from two or four H_2O's per unit; even these are absent in the spectra of the final samples.

* Supported by the ONR.
[1] Gladys A. Anslow, Faraday Society Discussion, No. **9**, 299 (1950).
[2] Gladys A. Anslow and Helen H. Fife, Phys. Rev. **83**, 192 (1951).

E10. Absorption by Beryllium in the Neighborhood of the *K* Edge. R. W. Johnston* and D. H. Tomboulian, *Cornell University.*—Following the experimental procedure described in a previous report,[1] measurements have been carried out on the absorption by metallic Be in the spectral range 70 to 250A. The absorbers consisted of metallic foils or layers of Be deposited on Zapon-wire mesh substrates by evaporation. The absorption curve reveals a sharp K edge located at approximately 110A, an intense absorption band centered at about 100A and the existence of secondary structure on the short wavelength side of the K edge. The present data have yielded consistent results for the mass absorption coefficient, where values range from approximately 1.0×10^4 to 1.6×10^5 cm^2/g in the above spectral range. In an effort to determine whether the dip at 100A was caused by the oxide, the absorption by BeO was investigated in this spectral range. It was found that the absorption by BeO was essentially uniform from 70A to 250A.

* Now at the Electronics Research Laboratory, Electronics Park, Syracuse, New York.
[1] E. M. Pell and D. H. Tomboulian, Phys. Rev. **76**, 172 (1949).

E11. Scattering of X-Rays by Atoms. G. PLACZEK, *Institute for Advanced Study.*—The incoherent scattering cross section of an atom for x-rays depends on the distance correlation of electron pairs which is caused by the Pauli principle[1] and by interaction between the electrons. The influence of the latter effect, which has so far been neglected, on the angular variation of the cross section will be discussed. It is also shown that the usual procedure of applying the Breit relativistic correction to the incoherent cross section has to be modified. This correction does not refer to the incoherent cross section, but to the part of the cross section which corresponds to scattering by free electrons.

[1] W. Heisenberg, Physik Z. **33**, 737, 1931.

E12. Scintillation Spectrometer for Measuring Total Energy of X-Ray Photons. M. R. CLELAND AND H. W. KOCH, *National Bureau of Standards.*—A large, liquid-scintillator, x-ray spectrometer has been successfully tested with bremsstrahlung from a 50-Mev betatron. The scintillator tank is so constructed that individual high energy x-ray photons will dissipate a major portion of their energy in the tank if initially directed along the major axis in the cylinder of liquid. The tank is 48 inches long and $7\frac{1}{4}$ inches in diameter and contains xylene with two grams per liter of terphenyl. Sixteen selected 5819 photomultiplier tubes are placed in a line parallel to the cylinder axis and on the surface of the cylinder. The combined photomultiplier output pulse is proportional to the total light produced by an x-ray photon expending its energy in the liquid. Monte Carlo calculations have been made to test the expected loss of x-ray energy by radiation escaping through the side or end of the xylene cylinder. The energy resolution is limited by the variation of light collection efficiency throughout the liquid. The variation was computed and measured to be of the order of plus or minus 10 percent. Bremsstrahlung spectra determined with the betatron operating between 25 and 44 Mev are in agreement with a corrected theoretical[1] energy distribution modified by the expected energy resolution.

[1] L. I. Schiff, Phys. Rev. **83**, 252 (1951).

THURSDAY MORNING AT 10:00

Horace Mann Auditorium

(E. O. SALANT presiding)

Cosmic Rays, I

F1. Altitude Effects on Cosmic-Ray Fine Structure. DANA T. WARREN, *Colorado A. and M. College.*—Measurements have been made on the detailed zenith-angle dependence of cosmic-ray intensity in the east and west azimuths in Fort Collins. The latitude is the same as that of Missouri, where previous fine structure observations have been carried out, but the altitude is about 4000 feet higher. Fluctuations have been observed similar to those in Missouri, amounting to two or three standard deviations in several instances. Comparison with the Missouri results in the same azimuths indicates that the relations are similar, though detailed identification is not yet possible. The agreement seems to be best if the comparison is made on the basis of the atmospheric path length, as would be expected if the effects are the result of atmospheric absorption. Evidence has also been obtained of the importance of side showers and other spurious effects in measuring the value of the exponent in the zenith-angle variation law.

F2. Latitude Variation of the Vertical Cosmic-Ray Intensity at High Altitudes.[1] W. F. G. SWANN AND D. W. SEYMOUR,[2] *Bartol Research Foundation.*—The results, uncorrected for meteorological effects, are shown in Table I, R begin the ratio of the maximum to minimum intensity at the altitudes expressed, in thousands of feet, by the subscripts.

Our 1946 results agree with those of Schein and Gill where, in both cases, the lead observer was placed above the apparatus. Our 1951 data with lead between the counter trays give much larger values of R. Our observations also show that the change in the hard component ratio for increasing depth of atmosphere is equal to the change for a mass equivalent increase of lead absorber.

TABLE I.

Date	Bartol (Telescopes) 1946	Bartol (Telescopes) 1951			Neher (Ion Chamber) 1948–49		Neher 1948–49	Schein and Gill 1947
Lead	16 cm[a]	0 cm	9 cm[b]	18 cm[b]	0 cm	11 cm[c]	0 cm	20 cm[a]
R_{33}	1.33	1.80	2.09	1.87				1.4
R_{30}		1.66	1.89	1.68	1.56	1.89	1.58	1.4
R_{25}	1.50	1.53	1.67	1.64				1.4

[a] Lead above telescope.
[b] Lead between counter trays.
[c] Lead around chamber.

[1] Assisted by the Joint Program of the ONR and the AEC and Brookhaven National Laboratory.
[2] Introduced by W. F. G. Swann.

F3. The Primary Cosmic Radiation at High Latitudes.* MARTIN A. POMERANTZ AND GORDON W. MCCLURE, *Bartol Research Foundation.*—Various properties of the new group of low energy primary cosmic-ray particles ($E<1.6$ Bev for protons) which enter the top of the atmosphere at geomagnetic latitudes north of 52° were investigated during the summer of 1950. Measurements were obtained with the same quadruple-coincidence counter trains used previously,[1] oriented either horizontally or vertically, and with pulsed ionization chambers biased to detect bursts exceeding 1 Po-α. No diurnal or temporal variations in the cosmic-ray intensity were detected, and no change between 1949 and 1950 was indicated. Flights were conducted with counter trains containing various thicknesses of interposed Pb absorber. No latitude effect was revealed for cosmic rays traveling in the horizontal direction at the highest altitudes attained (~9 mm of Hg). A similar result was obtained in the case of bursts detected by the ionization chambers. The data permit conclusions to be drawn regarding the horizontal component, the solar dipole-moment, the nature of the low energy spectrum, as well as nuclear disintegrations and primary heavy nuclei.

* Supported by the joint program of the ONR and AEC. Field Expedition sponsored by the National Geographic Society.
[1] M. A. Pomerantz, Phys. Rev. **77**, 830 (1950).

F4. Scintillation Counter Measurements of the Cosmic Radiation.* R. V. Adams, Dorothy Montgomery Hirshfelder, J. A. Northrop, and N. R. Whetten, *Yale University.*—Scintillation crystals, operated in coincidence with Geiger counters, have been used to detect cosmic radiation at New Haven† and at Climax, Colorado. Four cubical anthracene crystals were cemented together to form a phosphor with a 3×3-cm² horizontal surface and a 1.5-cm depth. Pulses from two 1P28 photomultiplier tubes, placed on either side of the phosphor, were added and amplified to obtain pulse-height distribution curves. Above and below the phosphor were placed Geiger-counter trays, each having a sensitive area of 400 cm². Pulse-height distributions, obtained for several thicknesses of lead absorber which were placed above the apparatus, indicate that the particles detected at sea level consist principally of the meson component. Between sea level and 3500 meters elevation there is a factor of 2 increase in the number of small pulses, while the largest pulses increase by a factor of about 20. Preliminary experiments have also been carried out at Climax with NaI crystals in coincidence with Geiger counters. Measurements of counting rates for three sizes of crystal have been made to determine whether the particles detected are principally (1) single minimum ionizing particles, (2) showers, or (3) stars.

* Supported in part by the joint program of the ONR and AEC.
† The sea level experiments were carried out by Dorothy Montgomery Hirshfelder, who is now at Madison, Wisconsin.

F5. An Analysis of the Hard Component of Cosmic Rays in the Upper Atmosphere.* M. A. Clark, *Massachusetts Institute of Technology.*—An experiment has been carried out to study the hard component of cosmic rays in the upper atmosphere. The balloon-borne apparatus consisted of a lead absorber, three trays of Geiger-Mueller tubes, a coincidence circuit, and radio telemetering equipment. The arrangement yielded a separation of the hard component into two groups, depending on whether or not the particles suffered nuclear interactions on traversing 20 cm of lead. The rate of occurrence of particles in these two groups has been determined as a function of atmospheric depth from 16 gm-cm^{-2} to 400 gm-cm^{-2}. An analysis of the results provides information about the numbers of mu-mesons and nucleons in the upper atmosphere.

* This work has been supported in part by the joint program of the ONR and AEC.

F6. Diurnal Effect on Cosmic-Ray Neutrons at High Altitudes.* M. J. Swetnick, H. A. C. Neuburg, and S. A. Korff, *New York University.*—A neutron counting arrangement was flown at high altitudes from day into night by means of a plastic balloon[1] in order to investigate whether there existed a diurnal effect on cosmic-ray neutrons. The flight was launched at 4:30 P.M. from Minneapolis, Minnesota. At 6:00 P.M. the balloon leveled off at 87,000 feet and floated until sunset (approximately 8:00 P.M.) Just after sunset the balloon descended to 84,000 feet where it remained for three hours. The experiment consisted of an enriched and a regular BF_3 counter, associated circuitry, and a pressure recording device. To prevent corona discharge, the counters and high voltage were pressurized. The apparatus was placed in a styrofoam box along with containers of warm water to prevent it from freezing. Data were radioed to a ground station. The average counting rate at 87,000 feet obtained before sundown was determined, as was the average counting rate at 84,000 feet after sundown. Because of the difference in floating levels during day and night the average day counting rate at 87,000 feet was corrected to 84,000 feet. The correction was made by an interpolation process using the slope calculated from the daytime counting rate *versus* pressure curve. On comparing the day and night counting rates at 84,000 feet an average diurnal effect of 17 ± 7 percent was found. Such an effect could be produced by neutrons coming directly from the sun or by a diurnal effect in the neutron producing component at high elevations.

* This work was assisted by the joint program of the ONR and AEC.
[1] Flight service carried out by Project Skyhook.

F7. Cosmic Ray Neutron Production.* Arthur Beiser, *New York University.*—Much information on the production of neutrons by the cosmic radiation in air and in other absorbers can be obtained from a consideration of information determined from nuclear emulsion experiments. These neutrons are produced in nuclear disintegrations ("stars"), and their rates of production under various circumstances may be calculated by properly interpreting: (1) the alpha-particle-proton and deuteron-proton ratios in stars and their variation with atomic weight and star size; (2) the dependence of prong multiplicity upon various parameters, including absorption depth; (3) the cross sections for star production in different materials; and (4) the extrapolation of such rates of production to include prong multiplicities smaller than three. Calculations of this nature have been performed previously but were inaccurate because of certain omissions and misconceptions which will be discussed. The present method has been employed in the determination of neutron production rates under several experimental conditions, and these values will be compared with values obtained under similar conditions by the use of counter techniques.

* This work was supported by the joint program of ONR and AEC.

F8. Collision Mean-Free-Path of Secondary Particles from Nuclear Interactions.* M. Annis and H. S. Bridge, *Massachusetts Institute of Technology.*—A cloud-chamber experiment has been performed at Echo Lake, Colorado (10,600 feet) to measure the collision mean free path of the secondary particles from nuclear interactions. An estimate has been made that 75 percent of these secondary particles are mesons, and that 25 percent are protons. Several events have been interpreted as either "nuclear stoppings" or $\pi^+\rightarrow\pi^0$ charge exchange. Use has been made of the Olbert calculations (see following abstract) on multiple scattering to differentiate clearly between multiple Coulomb scattering and nuclear scattering. The average kinetic energy of the secondary protons and mesons was estimated to be 800 Mev. The collision mean-free-path in Pb and Al has been found to be geometrical within the statistical errors of about 25 percent.

* Supported in part by ONR.

F9. Application of the Multiple Scattering Theory to Cloud-Chamber Measurements, I. Stanislaw Olbert, *Massachusetts Institute of Technology.*—We discuss in this paper some theoretical questions concerning the application of the multiple scattering theory to the analysis of cloud-chamber pictures: (a) We modify Molière's theory taking into consideration the finite nuclear dimensions. For this purpose, we assume that the probability of single scattering goes abruptly to zero for angles greater than $\phi_0=a\phi_m/r_n$, where a is the Thomas-Fermi radius of the atom, r_n the radius of the nucleus, and ϕ_m is the screening angle as derived by Molière. The cut off affects especially the "tail" behavior of the distribution function for the multiple scattering. While Molière's function decreases as ϕ^{-3} for projected angles of scattering, ϕ, large compared with rms angle, our distribution function decreases approximately as a Gaussian function of $(\phi-\phi_0)$. (b) We derive the distribution function for the mean value of the square angle of scattering in the plates of a multiple-plate cloud-chamber. (c) We estimate quantitatively the effect of observational errors on the distribution functions considered in (a) and (b).

F10. Application of the Multiple Scattering Theory to Cloud-Chamber Measurements, II. MARTIN ANNIS, HERBERT S. BRIDGE AND STANISLAW OLBERT, *Massachusetts Institute of Technology.*—When a particle comes to rest in a multiple-plate cloud-chamber, for each plate traversed, one can define a scattering variable, $\zeta=\phi R^\alpha$, where ϕ is the projected angle of scattering in the plate, R is the residual range, and α is the coefficient in the empirical relation, $p\beta\alpha R^\alpha$ (p and β are momentum and velocity of the particle). The variable ζ obeys a distribution function analogous to that for the scattering angle of mono-energetic particles (*cf.* preceding paper). The parameters entering in this function depend only on the mass of the particle. We have applied the method outlined above to an analysis of the secondary particles resulting from high energy nuclear interaction of cosmic rays. We have separated mesons (π or μ) from protons on the basis of the mean value of ζ^2 for the various plates traversed by each particle. We have then plotted two distribution curves, including the measured values of the scattering variable, ζ, for all particles of each group. We have thus obtained a value of 1860_{-130}^{+170} electron masses for protons, and 230_{-29}^{+32} electron masses for mesons.

Invited Paper

F11. Cosmic Rays Underground. E. P. GEORGE, *Birkbeck College, University of London.* (30 min.)

THURSDAY AFTERNOON AT 2:15

Horace Mann Auditorium

(S. A. KORFF presiding)

Cosmic Rays, II

G1. High Energy Nuclear Interactions in Lead.* E. M. HARTH,† F. E. FROEHLICH, AND K. SITTE, *Syracuse University.*—A large cloud chamber containing $8\frac{1}{2}$-in. lead plates was run in conjunction with a 134-counter hodoscope placed directly underneath the chamber. Thus it was possible to study details of the interactions produced in the chamber from the photographs and to follow the further development of the "nuclear cascade" through about 600 g/cm² of lead in the hodoscope. In particular, the "integral path length" of the nuclear cascade is a measure of the energy of the primary particle. The analysis of some 400 events shows over a primary energy interval from about 1–2 Bev to about 10 Bev a variation of the primary mean free path from 220 g/cm² to 160 g/cm², while the ratio of the numbers of charged mesons and of protons increases from about 0.4 to 1.5, and the ratio of charged to neutral mesons remains constant ($\sim$2). The statistics are not good enough to decide whether the mean free path of the secondaries also varies with the primary energy; a mean value of 270 g/cm² was observed. A distribution function of the energy transfer as a function of the energy can be derived: It shows a low probability for small transfers, followed by a rather flat section slowly decreasing for large fractional transfers.

* Supported in part by the AEC.
† Now at the NRL, Washington, D. C.

G2. The Ratio of Soft to Hard Particles in Air Showers.* K. SITTE, *Syracuse University.*—Some doubt has recently been cast upon the validity of the customary procedure of identifying the energy spectrum of air showers with the primary spectrum. These two distributions would differ if the mechanism of energy transfer to the electron component itself varied with energy. As a result, one would then expect a variation in the amount and composition of the penetrating component of extensive showers. An experiment was therefore carried out to compare the penetrating component of 10^{12} ev showers at Mt. Evans, altitude 4300 m, with that of 10^{13} ev showers at Echo Lake, altitude 3260 m. The results are: (number of penetrating particles)/(number of electrons) $=(2.0\pm0.11)\times10^{-2}$ at Mt. Evans, and $=(1.30\pm0.12)$ at Echo Lake; (number of N-particles)/(number of μ-mesons) ≈2.0 at Mt. Evans, and ≈0.7 at Echo Lake. If the change in the composition due to nuclear interactions and decay is accounted for, one finds that the ratio of μ-mesons to electrons is about equal for the two energies, while the ratio of N-particles to μ-mesons is slightly larger for the lower energy. The results are therefore consistent with a uniform picture for the processes involved, demanding only a slightly increased multiplicity of meson production for the higher primary energy.

* Supported in part by the AEC.

G3. Large Air Showers at Airplane Altitudes.* HENRY L. KRAYBILL, *Yale University.*—The change of extensive shower rate with variation of counter area of a threefold coincidence detector has been measured at pressure altitudes of 25,000 ft, 30,000 ft, and 33,000 ft between Lima, Peru, and Rome, New York, in a B-29 airplane flown by the U. S. Air Force. Coincident discharges of individual counters in a fourth tray, located centrally with respect to the other three trays, were recorded for each shower. The area of the counter trays was varied from 80 cm² to 560 cm². In this range, measured mean values of γ ($\gamma=\ln C/d\ln A$, where C is the shower rate and A is the counter area) are 1.45 at 25,000 ft, 1.5 at 30,000 ft, and 1.56 at 33,000 ft.

* Supported by the joint program of the ONR and AEC.

G4. Monte Carlo Study of Shower Production. ROBERT R. WILSON, *Cornell University.*—Monte Carlo calculations of cascades produced by photons and electrons incident on lead have been completed for initial energies in the range from 20 to 1000 Mev. The results will be exhibited and are quite different from those by conventional cascade theory, as would be expected for lead. The number of electrons near the shower maximum is considerably less and the shower penetrates farther into the lead. The Monte Carlo results have also been corrected for the effects of multiple scattering on the motion of the electrons.[1] The effects are quite different depending on the measurement considered. Thus, ionization current measurements are only slightly changed (the transition curves are foreshortened by a nearly constant amount), but the number of electrons counted behind successive lead plates in a cloud chamber can be reduced by as much as 50 percent by multiple scattering.[2] The comparison of the calculated curves with the ionization measurements of Blocker *et al.*[3] and the cloud-chamber measurements of Shapiro[2] is satisfactory.

[1] R. R. Wilson, Phys. Rev. **84**, 100 (1951).
[2] A. M. Shapiro, Phys. Rev. **82**, 307 (1951).
[3] Blocker, Kenney, and Panofsky, Phys. Rev. **79**, 419 (1950).

G5. Characteristic Functionals in Cascade Theory.* W. T. Scott, *Smith College*.—The enormous complexity of cascade shower theory has been somewhat unraveled by the introduction of master functions[1] giving the probability of finding N particles of specified energies at depth t, and by the use of certain generating functions.[2] Further progress seems possible through the use of characteristic functionals.[3] We define $C[\sigma(E);\ E_0,\ t]=\Sigma_N(1/N!)\int_0^\infty dE;\ldots\int_0^\infty dE_N\sigma(E_1)\ldots\sigma(E_N)\times P_N(E_1,\ E_2,\ \ldots E_N;\ E_0,\ t)$ as a functional of an arbitrary function $\sigma(E)$. P_N is the master function, E_0 the initial energy. From C we may obtain by functional differentiation and suitable choice of σ all subsidiary functions of interest. The fact that a shower propagates itself from any depth t' as a new starting point leads to a functional iteration: $C[\sigma;\ E_0,t+t']=C[C[\sigma;\ E,\ t];\ E_{0,}t']$. Two equations for $\partial C/\partial t$ may be derived from this and from the elementary multiplication and energy loss laws. One is a linear functional equation and the other ("adjoint") is a nonlinear differential-integral equation. Two examples will be given for which C can be found explicitly, and various theorems stated.

* Research performed at Brookhaven National Laboratory, under AEC auspices.
[1] W. T. Scott, Phys. Rev. **82**, 893 (1951); H. J. Bhabha, Proc. Roy. Soc. (London) **A202**, 301 (1950).
[2] L. Jánossy, Proc. Phys. Soc. (London) **A363**, 241 (1950).
[3] M. S. Bartlett and D. G. Kendall, Proc. Cambridge Phil. Soc. **47**, 65 (1951). These authors define the characteristic functional differently.

G6. Cosmic-Ray Stars Produced in the Gas of a Cloud-Ion Chamber. Fielding Brown, R. Ronald Rau, George T. Reynolds, *Princeton University*.*—Using a cloud-ion chamber, which has been described previously,[1] several hundred stars have been observed in the cloud-chamber gas during 40 days of operation at Echo Lake, Colorado. The chamber was filled successively with neon, argon, and krypton, and operation was found to be feasible with each gas. Statistical analysis of the resulting data is in progress and preliminary results on prong angles and numbers distributions will be given.

* Supported by the joint program of the ONR and AEC.
[1] Brown, Rau, and Reynolds, Bull. Am. Phys. Soc. **26**, No. 6, 16 (1951).

G7. *Z*-Dependence of Cross Section and Energy in Cosmic-Ray Stars.* Ian Barbour, *Kalamazoo College*.—Cosmic-ray induced disintegrations of nuclei of metal foils "sandwiched" between face-to-face Ilford G5 emulsions exposed at balloon altitudes have been studied using Au, Pt, Sn, Cu, Ni, and Al. After removal of the foil and development, each pair of plates is reconstructed in its original orientation and scanned for stars originating in the metal,[1] and then separated again for re-examination under high magnification. Previous results[2] have been extended and integral cross sections for stars of various sizes as they vary with the atomic number of the target nucleus will be presented. Measurements on the location and dip angle of each star track allow comparison with the expected angular distribution and calculation of the path length in the foil for each particle. Grain density measurements enable approximate energy distributions and excitation temperatures to be obtained.

* This work has been aided by a Cottrell Grant from the Research Corporation.
[1] I. Barbour and L. Greene, Phys. Rev. **79**, 406 (1950).
[2] I. Barbour, Phys. Rev. **82**, 280 (1951).

G8. Absorption in Carbon of Protons in the Cosmic Radiation at Sea Level.* J. Ballam,† *University of California*.—The absorption mean free path of protons of energies between 150 and 570 Mev was measured by placing carbon absorber above two counter-controlled cloud chambers, one in a magnetic field of 4800 gauss and the other containing copper plates. The protons were identified by a measurement of their curvature and range. A counter tray, connected to a neon indicator, was placed above the carbon and put in coincidence with the trays which triggered the cloud chambers. The incident energy spectrum was obtained from the work of Mylroi and Wilson.[1] By observing the numbers of protons stopping in the lower cloud chamber after passing through various thicknesses of carbon and correcting for the ionization loss, the ratio of the number stopping to the number incident was calculated, and the mean free path was determined to be $L=167$ g/cm^2 with a lower limit of 136 and an upper of 300. It was also found that about fifty percent of the protons stopping under 44 and 88 g/cm^2 of carbon were produced therein by incident neutral particles, thus confirming the work of Goldwasser and Merkle.[2]

* Assisted by the joint program of the ONR and AEC.
† Now at Princeton University, Princeton, New Jersey.
[1] Mylroi and Wilson, Proc. Phys. Soc. (London) **A64**, 404 (1951).
[2] Goldwasser and Merkle, Phys. Rev. **83**, 43 (1951).

G9. The Disintegration of *V*-Particles.* C. J. Karzmark, R. W. Thompson, and Hans O. Cohn, *Indiana University*.—The cloud-chamber experiment on penetrating showers previously reported[1] has been continued in order to increase the amount of quantitative data available on *V*-particles. A 12-inch diameter magnetic cloud chamber under a layer of lead is triggered by an array of counters which responds preferentially to events in which two or more penetrating particles are produced in the lead above the chamber. Certain modifications and improvements of the apparatus have been made in the interest of reproducible accuracy of measurement over an extended period of time. At regular intervals, sets of no-field tracks are taken in order to check that track distortions produced by the chamber are negligible. Up to the present time, a total of 1053 stereoscopic photographs of penetrating showers of multiplicity greater than or equal to 3 have been obtained. Among these, a total of 35 neutral *V*-particle disintegrations of both types have been found, and alsc a few examples of the rarer charged *V*-particle disintegration. In one very energetic penetrating shower, two neutral *V*-particle disintegrations occur. The experiment is in progress and the results to date on the nature of the disintegration fragments, the disintegration schemes, and the *Q*-values will be presented.

* Assisted by a grant from the Frederick Gardner Cottrell Fund of the Research Corporation and by the Office of Army Ordnance Research.
[1] Thompson, Cohn, and Flum, Phys. Rev. **83**, 175 (1951).

G10. Nuclear Interaction of Fast μ-Mesons.* H. C. Wilkins† and R. D. Sard, *Washington University* (Introduced by A. L. Hughes).—Neutron production by the nuclear interaction of fast μ-mesons with Pb has been studied at a depth of 2000 g cm^{-2} underground. An array of G-M counters above and below the absorber registered separately penetration by unaccompanied μ-mesons and those accompanied by one or more other ionizing particles. Neutrons were detected by an array of neutron counters below the absorber. The counting rates for 1, 2, and 3 neutrons detected in delayed coincidence with the penetrating event gave information about the mean multiplicity of neutrons per interaction and the cross section for the interaction. Upper and lower limits on the inelastic μ-meson-nucleon cross section are given independent of the rather uncertain value of the neutron multiplicity. A discussion will be given of the relationship of these limits to the results previously reported by Cocconi and Tongiorgi; Amaldi and Fidecaro; and Braddick, Nash, and Wolfendale.

* Supported in part by the ONR.
† AEC Predoctoral Fellow.

G11. Production Cross Section and Energy Spectrum of the π_0 Meson (Cosmic-Ray Measurement). G. SALVINI AND Y. KIM, *Princeton University*.*—The properties of neutral mesons are studied on the basis of the successive electromagnetic interactions in the closely spaced C and Pb plates of a cloud chamber of dimensions $18\times 18\times 8$ inches. The nuclear events were detected in an almost unbiased way by sodium iodide crystals.[1] The experiment was performed at Echo Lake, Colorado. The distribution in energy of the π_0's does not differ appreciably from the energy distribution of the charged π-mesons given by the Bristol Group. The table summarizes the cross section for production of π_0's, and the ratio $(\pi_+ + \pi_-)/\pi_0$.

Energy of producing protons (Bev)	0.345	0.8–2	>2
σ_{prod} of the π_0	$1/200\ \sigma_{geo}$†	$0.16\ \sigma_{geo}$	$0.6\ \sigma_{geo}$
Ratio $(\pi^+ + \pi^-)/\pi_0$	...	...	2.8 ± 0.6

The pictures are now being analyzed to estimate the mean free path in C and the cross section for charge exchange in C and Pb of the π-mesons.

* Supported by the joint program of the ONR and AEC.
[1] G. Salvini and George T. Reynolds, Phys. Rev. **83**, 198 (1951); G. Salvini, Nuovo Cimento, **8**, (October, 1951).
† Burton J. Moyer, private communication.

G12. Momentum Spectra of Cosmic-Ray Mesons and Protons at Sea Level and 3.4 km Altitude.* W. L. WHITTEMORE AND R. P. SHUTT, *Brookhaven National Laboratory*.—A cloud-chamber experiment has been performed at sea level and 3.4 km altitude to collect data on the momentum and scattering distributions of 15,000 mesons and protons. Electrons are recognized by the showers they produce in lead inside the chambers and thus can be excluded. The momentum distribution at sea level is in accord with the results of others. A comparison of the sea level and altitude spectra indicates that only few mesons, if any, are produced below 3.4 km up to momenta of 10 Bev/c. The distributions for negative particles have also been used to compute the production spectrum of mesons assuming that production of the fast mesons observed takes place within the top 125 g/cm^2 of the atmosphere. The resulting differential momentum distribution at production can be represented adequately as a power law with an exponent equal to 2.82 ± 0.07 in good agreement with previous published results. The relative numbers of positive and negative particles agree well with those of other workers at sea level. At altitude this $+/-$ ratio becomes quite large towards the lower momenta (up to 2.4 as against 1.2 at sea level). Assuming that the difference between the sea level and altitude ratios is due to protons, one can compute that above 0.2 Bev/c protons form 20 ± 3 percent of all ionizing particles at 3.4 km. From the $+/-$ ratios the proton momentum spectrum has been calculated.

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

G13. A Redetermination of Mesotron Mean Lifetime as a Function of Momentum. D. W. SEYMOUR AND W. F. G. SWANN, *Bartol Research Foundation* (Introduced by W. F. G. Swann).—Calculations of mesotron mean lifetime were carried out for various momenta by comparing differential lead absorption measurements at two different elevations. An additional lead absorber within the upper counter telescope was used to compensate for the absorption of the air column. The value of the rest mean life thus obtained is 2.3×10^{-6} sec, in reasonable agreement with what has been considered the most precise value of 2.15×10^{-6} sec obtained by Rossi and Nereson by another method.[1]

[1] B. Rossi and N. Nereson, Phys. Rev. **62**, 417 (1942).

G14. Multiplicity of Mesons Produced in Lead.* JOHN LINSLEY† AND E. P. NEY, *University of Minnesota*.—A number of interactions of very energetic particles, presumably primary cosmic-ray protons, have been observed in the lead plates of a counter-controlled cloud chamber at atmospheric depths less than 180 g/cm^2 (altitudes greater than 40,000 ft). The apparent multiplicity of meson secondaries was greater than 10 in all of 11 events and greater than 20 in 4 of the events, while the corresponding incident proton energies were less than 100 Bev and 200 Bev respectively for the two groups. The data agree with an observation of Hartzler[1] that considerably more mesons are produced in heavy nuclei than Fermi's theory[2] predicts for single nucleon-nucleon collisions. The agreement is interesting since the experimental conditions were quite different. The large multiplicity of mesons supports the opinion that a nucleon-meson cascade develops to a considerable extent within heavy nuclei in such events.

* Research supported by the ONR.
† Now at the University of Virginia.
[1] A. J. Hartzler, Phys. Rev. **82**, 359 (1951).
[2] E. Fermi, Prog. Theor. Phys. **5**, 570 (1950); Phys. Rev. **81**, 683 (1951).

THURSDAY AFTERNOON AT 2:15

Pupin 301

(R. E. MARSHAK presiding)

Scattering of Elementary Particles and Simple Nuclei

H1. Scattering of Gammas by Bound Electrons.* J. S. LEVINGER, *Louisiana State University*.—Knowledge of the amplitude for elastic scattering of gamma-rays (Co^{60}, 1.33 Mev, and ThC″, 2.62 Mev) by bound electrons (Sn and Pb) is essential for the analysis of Wilson's experiment[1] on Delbruck scattering. Franz[2] showed that, subject to many approximations, the coherent electronic scattering amplitude is that given by the form factor calculation. The general expression[3] for the scattering amplitude, subject to the single approximation of a free intermediate state for the electron, is difficult to evaluate. The present author has evaluated this expression by an expansion in q/mc, where q is the photon change of momentum, and m is the electron mass. For $q/mc < 1.8$, the scattering amplitude is slightly larger than that of the form factor calculation and independent of the photon energy. Numerical results for this ratio for scattering of gammas by K electrons of tin are: ratio $=1.1$ for $q/mc=1$; ratio $=1.2$ for $q/mc=1.8$.

* Assisted by the ONR.
[1] R. R. Wilson, Phys. Rev. 82, 295 (A), (1951).
[2] W. Franz, Z. Physik 98, 314 (1936).
[3] Obtained by H. A. Bethe, F. Rohrlich, P. Greifinger, and the present author.

H2. Nuclear Scattering of 17-Mev Gamma-Rays. M. B. Stearns, *Cornell University.*—Measurements of the elastic and inelastic nuclear scattering of gamma-rays produced by the Li (p,γ) reaction have been made. The gamma-ray detector was a NaI crystal. To reduce backgrounds, an anticoincidence ring of Geiger counters were placed around the crystal. Scattering from Bi, Pb, Sn, and Cu was measured at an angle of $116°\pm 17°$. The following absolute differential cross sections were obtained:

	Bi	Pb	Sn	Cu
I. Elastic ($E>14.4$ Mev)	0.82 ± 0.22	0.53 ± 0.14	0.20 ± 0.049	0.044 ± 0.020
II. Inel. El. ($E>12.3$ Mev)	1.47 ± 0.22	1.21 ± 0.16	0.33 ± 0.049	0.066 ± 0.016

The cross sections in row I are the measured values. The cross sections in row II are lower limits, the upper limits being about 3 times these values. All errors are standard deviations. Bremsstrahlung, from secondary electrons in the scatterers, was negligible in the foregoing measurements. The elastic scattering cross sections varied with Z as $Z^{2.5\pm.5}$ while the inelastic scattering varied at a rate greater than $Z^{2.9\pm.3}$. The elastic scattering results combined with observed integrated γ–n cross sections for Cu (about 0.9 Mev-b.) is in agreement with a gamma-ray absorption curve having a width of 4–6 Mev centered near 18 Mev. Appreciable inelastic scattering was observed indicating that narrow one-level theories such as the Goldhaber-Teller theory cannot be correct.

H3. Angular Distribution of Protons Scattered by 1.0 to 3.02-Mev Deuterons.* G. D. Freier, W. R. Stratton, R. J. S. Brown, H. D. Holmgren, and J. L. Yarnell, *University of Minnesota.*—The differential cross section for protons elastically scattered by an incident deuteron beam has been measured in the energy range 1.00 and 3.02 Mev. This corresponds to an extension of the Los Alamos[1] p, d scattering data from 1.51 to 0.50 Mev. An incident deuteron beam from the Minnesota electrostatic generator was passed through a small volume scattering chamber[2] filled with hydrogen. Recoil protons were detected in a proportional counter at laboratory angles less than 90° and scattered deuterons at angles less than 30°. The angular range of data varied with energy. The maximum angle (center of mass system of coordinates) at all energies is 126.4°. The minimum angle at 3.02 Mev is 60° and at 1.00 Mev, 90°. Data at 3.02 Mev agree, within errors, with previous data.[1]

* Supported by the joint program of the ONR and AEC.
[1] Sherr, Blair, Kratz, Bailey, and Taschek, Phys. Rev. 72, 622 (1947).
[2] Claassen, Brown, Freier, and Stratton, Phys. Rev. 82, 589 (1951).

H4. Angular Distribution of 1.5 to 3.0-Mev Deuterons Scattered by Tritium Nuclei.* W. R. Stratton, G. D. Freier, G. R. Keepin, D. Rankin, and T. F. Stratton, *University of Minnesota.*—The differential cross section for deuterons scattered elastically by tritium has been measured in the energy range 1.50 to 3.02 Mev using the Minnesota electrostatic generator as a source of monoenergetic deuterons. The small volume scattering chamber, previously described,[1] has been modified slightly by increasing its volume to about 200 cm³. A proportional counter detected both scattered deuterons and recoil tritons, and measurements of the cross section were obtained between 45° and 125° in the center-of-mass system of coordinates. The cross section as a function of angle displays a typical minimum near 90° in the center-of-mass coordinate system. The cross section at this minimum decreases monotonically with increasing deuteron energy.

* This work is supported by the joint program of ONR and AEC.
[1] Claassen, Brown, Freier, and Stratton, Phys. Rev. 82, 589 (1951).

H5. Proton-Alpha Particle Scattering Using Photographic Techniques.* W. E. Kreger, R. O. Kerman,† and W. K. Jentschke, *University of Illinois.*—The differential cross section of proton-alpha-particle scattering at 5.82 ± 0.06 Mev has been measured using nuclear research plates to detect the scattered protons and the recoil alpha-particles. Values of the differential elastic scattering cross section have been determined for twenty-eight center-of-mass angles between 16° and 154°. The over-all uncertainty in these values is approximately 1.5 percent. A phase-shift analysis of the data has been made following the method of Critchfield and Dodder.[1] No evidence for phase-shifts in collisions with angular momenta greater than that for P-waves has been found. The analysis gives an S-wave phase-shift of $-46°\,40'$, a $P_{\frac{1}{2}}$-wave phase-shift of $34°\,42'$ and a $P_{\frac{3}{2}}$-wave phase-shift of $180°\,47'$ on the inverted doublet model.

* Assisted by the joint program of the ONR and AEC.
† Now at Kalamazoo College, Kalamazoo, Michigan.
[1] Critchfield and Dodder, Phys. Rev. 76, 602 (1949).

H6. Precision Alpha-Alpha Scattering at Low Energies. D. B. Cowie, N. P. Heydenburg, G. M. Temmer,* and C. A. Little, Jr., *Department of Terrestrial Magnetism.*—The differential cross section for the elastic scattering of alpha-particles (He^+) in helium in the energy range 400 kev to 950 kev in 100 kev steps has been measured with the electrostatic generator of the Department of Terrestrial Magnetism over the angular range 10° to 45° (lab). The large currents furnished by a new rf ion source have made this energy range of alpha-particles accessible to experiment. Early work along these lines was confined to the higher energies of natural alpha-emitters and was primarily concerned with the verification of the effects of the identity and boson character of alpha-particles on Coulomb scattering,[1] although some "anomalous" scattering has been observed[2] below 2 Mev. The scattering apparatus used is similar to that of Heydenburg *et al.*[3] with a fixed monitor counter at 15° and helium pressure of 1 mm Hg. The precision attained is about 1 percent. The equipment was tested by scattering from argon gas; pure Rutherford scattering was obtained. At 850 kev the deviations from Mott scattering amount to as much as 8 percent. Phase shift analysis of the results is now in progress. This work is being extended up to 3 Mev with our pressurized electrostatic generator as well as to lower energies in the hope of localizing the ground state of Be^8.

* From the National Bureau of Standards.
[1] Chadwick, Proc. Roy. Soc. (London) A128, 114 (1930); Blackett and Champion, Proc. Roy. Soc. (London) A130, 380 (1931).
[2] See for instance Mohr and Pringle, Proc. Roy. Soc. (London) A160, 190 (1937).
[3] Heydenburg, Hafstad, and Tuve, Phys. Rev. 56, 1078 (1939).

H7. Neutron-Proton Total Cross Section.* E. M. Hafner, D. H. Frisch,† C. E. Falk, T. Coor, and W. F. Hornyak, *Brookhaven National Laboratory.*—A precise determination of the total $n-p$ cross section is being carried out with $D-D$ neutrons. Deuterons of 1380 kev enter a gas target of about 100-kev thickness. The exact target thickness, as well as the thickness and nonuniformity of the 0.00005-inch nickel entrance foil, are measured by using the $F^{19}(p,\alpha,\gamma)O^{16}$ resonance at 873.5 kev. The scatterer and detector are located in the forward direction. The detector is a 1-inch diameter button[1] of molded lucite and ZnS at 20 inches from the target. The background with this system is low and consists mostly of $D-D$ neutrons scattered in the room. Cross sections are determined for 16 graphite scatterers and 11 polyethylene scatterers of different diameters. By extrapolating the resulting functions to zero diameter it is possible to correct $\sigma(n, p)$ for geometrical effects. The scatterers are chemically analyzed and the graphite tested for water vapor absorption. The electronics is continuously checked by using two independent discriminators and scalers on both the monitor and the detector.

* Research carried out under the auspices of the AEC.
† M.I.T.
[1] W. F. Hornyak, Rev. Sci. Instr. (to be published).

H8. Angular Distribution of 215-Mev Neutrons Scattered by Protons.* G. L. GUERNSEY, *University of Rochester.*—The neutron beam obtained by intercepting the circulating protons of the University of Rochester 130-in. synchrocyclotron has been used for neutron-proton scattering experiments. An anthracene scintillation counter telescope has been employed for detection of the scattered protons at laboratory angles of 0° to 50°, with one of the counters serving as a differential energy spectrometer. The angular dependence obtained for the neutron-proton cross section at 215 Mev is in general agreement with the results of the Berkeley 90[1] and 260[2] Mev experiments.

* Supported by the AEC.
[1] Hadley, Kelly, Leith, Segrè, Wiegand, and York. Phys. Rev. **75**, 351 (1949).
[2] Kelly, Leith, Segrè, and Wiegand, Phys. Rev. **79**, 96 (1950).

H9. Total Cross Sections of Carbon and Hydrogen for High Energy Neutrons.* GEORGE R. MOTT, GORDON L. GUERNSEY, AND BRUCE K. NELSON, *University of Rochester.*—Measurements of the total cross sections of carbon and hydrogen have been made at neutron energies of 97 ± 5, 117 ± 5, 140 ± 5, 156 ± 5, 180 ± 7, and 220 ± 10 Mev using a calibrated anthracene crystal as an energy sensitive detector for recoil protons. This proportional crystal was used as the fourth of a quadruple coincidence anthracene scintillation counter telescope which detected protons scattered at 20° from a polyethylene radiator exposed to the collimated high energy neutron beam from the University of Rochester 130-in. cyclotron. The methods used permit the simultaneous measurement of total $n-p$ cross sections over a continuous spectrum of neutron energies. The results obtained are in general agreement with previously reported experimental data, but approximately half the values predicted by Ashkin and Wu[1] ni the 100- to 200-Mev region using tensor force and the symmetrical Rarita-Schwinger exchange model in the rigorous scattering theory.

* Supported by the Joint Program of the AEC and ONR.
[1] J. Ashkin and Ta-You Wu, Phys. Rev. **73**, 973 (1948).

H10. The Total Elastic Scattering Cross Section of Nitrogen for Fast Neutrons.* W. M. PRESTON, P. H. STELSON, AND J. J. HINCHEY, *M. I. T.*—The total cross section of nitrogen has been measured for neutrons in the energy range 200 to 1800 kev, using scatterers of liquid nitrogen and of lithium azide. Eleven resonances were found in the compound nucleus N^{15}, with natural widths of from 3 to 54 kev. Nine of these can be identified with resonances previously known from the reactions $N^{14}(n,p)C^{14}$, $N^{14}(n,\alpha)B^{11}$,[1] or $C^{14}(p,n)N^{14}$.[2] Using the cross sections determined for these reactions, and from the present work, it is possible to assign J-values to many of the excited states of N^{15}. In some cases the parity also can be determined and the effective level spacing D_j computed for the different particles. It must be concluded that the quantities D_j, which contain implicitly the matrix elements for the transition, can vary by a factor of at least one hundred.

* This work was supported by the BuShips and the ONR.
[1] C. H. Johnson and H. H. Barshall, Phys. Rev. **80**, 818 (1950).
[2] Roseborough, McCue, Preston, and Goodman, Phys. Rev. **83**, 1133 1951).

H11. Scattering of Fast Neutrons. E. T. JURNEY AND C. W. ZABEL, *Los Alamos Scientific Laboratory.**—The scattering of fast neutrons by Al, Fe, Ni, Cr, Cu, Ta, Pb, and Bi was investigated by placing samples into the collimated fast neutron beam emerging from the plutonium fast reactor.[1] Small fission ionization chambers containing Np^{237} and U^{238}, respectively, served as neutron detectors. The angular distribution of the scattered neutrons was determined by moving these detectors around the samples. With the same detectors total cross sections were measured in simple transmission experiments. Scattered neutrons detected by the threshold fission counters will be called elastically scattered. If the integral over all angles of the differential elastic scattering cross section is subtracted from the total cross section, an inelastic collision cross section is obtained. Under the assumption that the inelastic scattering is isotropic, transport cross sections were calculated. For all the elements investigated the elastic cross section shows a strong forward maximum, for some elements an additional small maximum occurs near 100°.

* Work performed under the auspices of the AEC.
[1] Rev. Sci. Instr. **18**, 688 (1947).

H12. Inelastic Thermal Neutron Scattering in Lead.* A. W. MCREYNOLDS, *Brookhaven National Laboratory.*—In all crystals the total scattering cross section for neutrons of wavelength $\lambda<2d$ is dependent on crystalline effects, being the sum of Bragg diffraction and of inelastic and incoherent scattering. The inelastic component of scattering in lead has been studied as a function of temperature and wavelength in the region 2–5.7 angstroms. A beam of neutrons from the reactor was first passed through a mechanical velocity selector consisting of a series of rotating slotted Cd disks, then reflected from the (200) planes of a Pb single crystal to select a monoenergetic beam of high resolution. Measurements were then made of transmission through a Pb single crystal in the symmetry direction 111, 100, and 110, such that Bragg reflection occurs only at certain wavelengths. Between these diffraction regions the inelastic cross section, which varies more smoothly with wavelength, could be determined. Curves of inelastic cross section *vs* λ at 80° and 300°K show increase with decreasing wavelength and a proportionality to temperature in qualitative agreement with theory.

* Research carried out under contract with AEC.

H13. Neutron Energy Distributions from Be, C, and Pb Bombarded by 245-Mev Protons. B. K. NELSON,* *University of Rochester.*—The energy distribution in the forward direction from beryllium, carbon, and lead targets, and at 15° from beryllium and carbon targets, bombarded by 245-Mev protons has been obtained. The neutrons were allowed to bombard a hydrogenous radiator; scattered protons were observed in a scintillation counter relescope. The energy of these protons was determined by measuring the scintillation brilliance in the last crystal of the telescope; neutron energies were then deduced from the kinetics of the $n-p$ scattering. Entire scintillation pulse height spectra were observed at one time by a 24-channel pulse-height analyzer; neutron spectra were deduced from these. All the spectra observed were peaked, the energies at the peaks being about 215, 195, and 180 Mev for Be, C, and Pb, respectively, in the forward direction, and at about 175 and 165 Mev for Be and C at 15°. The carbon and lead spectra were more broadly peaked than the beryllium spectra, and the 15° spectra were broader than the 0° spectra, the full widths at half maximum being about 27 percent, 33 percent, and 49 percent for Be, C, and Pb 0° spectra, and about 40 percent and 42 percent for Be and C at 15°.

* Now at Project Lincoln, M.I.T.

THURSDAY AFTERNOON AT 2:15

Schermerhorn 501

(H. YUKAWA presiding)

Theoretical Physics, I

I1. Interaction between Quantized Electromagnetic Field and Classical Electron. I. R. SENITZKY, *Signal Corps Engineering Laboratories*.—Some quantum-theoretical aspects of the problem of an electron passing through an oscillating cavity have been considered by several authors[1-4] with simplifying assumptions (treating one of the interacting systems classically) and approximate calculations (using first-order perturbation theory or WKB method). The validity of some of the treatments[1,4] is questionable. In the present paper, the Hamiltonian for a quantized field and classical electron with prescribed motion is given. The resulting differential equations of motion are solved exactly by considering the corresponding difference equations. The solution yields some results contrary to those of an earlier theory[1] based on similar assumptions. If the number of photons in the cavity is large and the loss or gain due to the electron is small, the solution reduces to that of another theory[3] in which the field is treated classically and some, but not all, of the wave properties of the electron are considered.

[1] L. P. Smith, Phys. Rev. **69**, 195 (1946).
[2] C. Shulman, Phys. Rev. **82**, 116 (1951).
[3] J. C. Ward, Phys. Rev. **80**, 119 (1950).
[4] D. Gabor, Phil. Mag. **41**, 1180 (1950).

I2. Perturbation Treatment of Electromagnetic Problems. I. Theory. J. R. TERRALL AND BENJAMIN LAX,* *Air Force Cambridge Research Center*.—When inhomogeneous anisotropic media are under consideration, the equations for the electromagnetic field usually cannot be solved exactly in closed form. However, there are cases of practical interest for which the perturbation treatment developed so extensively for the study of quantum-mechanical problems can be profitably applied to the solution of Maxwell's equations. Starting with a complete set of characteristic wave functions of the vector wave equation in a bounded empty space as a basis, we derive expressions for the successive approximations to the electromagnetic field and to the eigenvalues of the wave equation when the perturbing medium, as described by a tensor function of position, is taken into account. We show also how media with the additional complication of time varying properties may be handled. Since the method permits calculation of the field to any order of approximation for generalized media, it is hoped that the usefulness of analysis in experimental applications may be extended. Usually, heretofore, the equivalent of first-order perturbation theory has been used, and this only, in application to isotropic media. Although the theory presented in this paper is specialized to media for which the magnetic permeability is that of empty space, the extension to more general media can be made.

* Now at the Research Laboratory of Electronics, M.I.T.

I3. Perturbation Treatment of Electromagnetic Problems. II. Applications. BENJAMIN LAX* AND J. R. TERRALL, *Air Force Cambridge Research Center*.—Complex inhomogeneous anisotropic media such as plasmas in a magnetic field, dielectrics, semiconductors, and paramagnetic and ferromagnetic materials in resonant microwave cavities have been studied. It is the object of this paper to demonstrate the application of perturbation theory in calculating the effect of these media on the eigenfunctions and eigenvalues of the cavity, i.e., on the electromagnetic field and the resonant frequency and Q of the cavity. A brief discussion of the degenerate perturbation theory as applied to a magneto-ionic plasma will be given, and experimental verification of the theory will be shown. A semiconductor with dielectric properties of large magnitude will be used as an example to demonstrate the need for considering second-order terms. Ferrites with anisotropic magnetic and large magnitude dielectric properties further generalize the application of perturbation theory to Maxwell's equations.

* Now at M.I.T.

I4. Perturbations of Atomic g Values. M. PHILLIPS, *Brooklyn College*.—A further investigation of the perturbation by excited core states of g values of atoms consisting of a single electron outside closed shells takes account of the spin orbit interaction of the excited core. Although the effect vanishes to lower orders than the 4th, and at least the first term in the expansion of the electrostatic interconfiguration interaction cancels even in that order, there is for alkali atoms a residual correction possibly large enough to account for the observed[1] g values for Cs and Rb, which are too large to be attributed to the intrinsic spin anomaly, δ_s. For smaller atomic numbers, however, the effect of perturbations is hardly within the limits of present experimental accuracy. Calculations have also been made for ^2P states: the effect in Ga is negligible, in accord with observed values,[2] but the anomalous observed[3] $g_J(P_{\frac{3}{2}})/g_J(P_{\frac{1}{2}})$ for In may be at least in part due to perturbations of this kind.

[1] P. Kusch and H. Taub, Phys. Rev. **75**, 1477 (1949).
[2] P. Kusch and H. M. Foley, Phys. Rev. **72**, 1256 (1947).
[3] A. K. Mann and P. Kusch, Phys. Rev. **77**, 435 (1950).

I5. On the Magnetic Hyperfine Structure.* R. STERNHEIMER, *Brookhaven National Laboratory*.—Equations have been obtained for the magnetic field at the nucleus due to the current induced in the electron core by an external valence electron. The magnetic field is written as $-4\mu_0(j/j(j+1))\times\langle r^{-3}\rangle_p(1+R_m)$ where $\langle r^{-3}\rangle_p$ is the average over the valence electron function assumed in a p state, R_m is the correction due to the core, μ_0 = Bohr magneton, j = angular momentum. R_m is of importance in obtaining the nuclear quadrupole moment Q from the value of the magnetic moment μ_I and the ratio b/a of the hfs splittings due to Q and μ_I. The electric field gradient at the nucleus $-(2/5)e\langle r^{-3}\rangle_p(1+R)$ which determines b, contains a similar term R for the distortion of the core by the valence electron. R is the sum of a negative shielding term R_d and an exchange term R_e. It is shown that $R_m\sim R_e$, and that the correction factor for Q is $\sim 1/(1+R_d)\times(>1)$, as predicted by the Thomas-Fermi model.[1] The valence electron interacts with the nuclear moment Q as shielded by the core, so that a greater value of Q is required to give the observed hfs splitting.

* Work performed under the auspices of the AEC.
[1] R. Sternheimer, Phys. Rev. **84**, 244 (1951).

I6. Mass Corrections to the Fine Structure of Hydrogen and Deuterium. E. E. SALPETER, *Cornell University*.—For a hydrogen-like atom with an infinitely heavy nucleus, the Dirac theory gives exact expressions for the fine structure and hyperfine structure. For a nuclear mass M no correction terms of relative order $\alpha(m/M)$ are obtained,[1] if the Breit equation and interaction term (only approximately Lorentz-invariant) is used. It is shown that corrections of relative order $\alpha(m/M)$

are obtained, both for fine structure and hyperfine structure, if a fully relativistic wave equation[2] for two-particle bound states is used. Two of these terms for the fine structure contain $\log\alpha$ as a factor and can also be derived from orthodox perturbation theory. One term is due to recoil energy of the electron in the intermediate state, neglected in the Breit term for the interaction between the electron and nucleus. The other is due to the exchange of *two* transverse quanta between the electron and nucleus, with the electron and nucleonic proton in negative energy intermediate states. These two terms give an energy shift of, very roughly, (m/M) and $(-3m/4M_p)$, respectively, times the Lamb shift.

[1] G. Breit and G. E. Brown, Phys. Rev. **74**, 1278 (1948); Breit, Brown, and Arfken, Phys. Rev. **76**, 1299 (1949).
[2] E. E. Salpeter and H. A. Bethe, Phys. Rev. **85** (to be published).

I7. A Fourth-Order Radiative Correction to Atomic Energy Levels. R. Bersohn, J. Weneser,* and N. M. Kroll.—The fourth-order radiative corrections to the elastic scattering of an electron by a specified external potential have been computed using the Dyson *S*-matrix formalism. Written as a modification in the interaction energy density of the electron with the external potential, the result must be of the form $C_1\overline{\Psi}\sigma_{\mu\nu}\psi F_{\mu\nu}{}^e+C_2(-ie\overline{\Psi}\gamma_\mu\psi)\Box^2A_\mu{}^e$ for slowly varying fields. C_1 is a correction to the anomalous moment of the electron and has already been computed.[1] We are concerned here with an evaluation of C_2. The contributions of fourth-order vacuum polarization to C_2 are being calculated elsewhere and therefore have been omitted here. The procedure is similar to that used in the evaluation of C_1. Although the contribution of each diagram diverges in the infrared, the total is finite and equal to $(\alpha^2/2\pi^2K_0{}^2)$ (0.52 ± 0.21). The indicated uncertainty arises from the fact that certain of the integrals have been estimated by the use of rigorous upper and lower bounds. It is expected that the actual error is considerably less than that indicated. Considered as a perturbing potential the C_2 term contributes to the level of a hydrogenic atom an energy $(2\alpha^6 2^4 mc^2)/(n^3\pi^2)\delta_{e0}(0.52\pm0.21)$, which corresponds to 0.24 ± 0.10 megacycles for the $2S$ level in hydrogen.

* AEC Predoctoral Fellow.
[1] R. Karplus and N. M. Kroll, Phys. Rev. **77**, 536 (1950).

I8. Electron Self-Energy. F. J. Belinfante, *Purdue University.*—The second-order electron self-energy in quantized Bopp electrodynamics[1] diverges quadratically due to intermediate states with Proca quanta of large negative energy. Pais[2] removed the divergence by subtracting a second-order perturbation through positive-energy Proca quanta (f_v-particles) instead of adding the second-order perturbation through negative-energy Proca quanta. Field-theoretically we obtain Pais' result by introducing an indefinite metric $^\circ\eta=(-1)^N$, where N is the number of Proca quanta *in interaction representation.* The Proca field (F) is self-adjoint $(F=F^\dagger)$ but not hermitian $(F\neq F^*)$, and $^\circ F^{(+)}\Psi_H=0$ replaces $^\circ F^{(-)}\Psi_H=0$.[1] Thence, $^\circ\eta\Psi_H=\Psi_H$ and $\Psi_H{}^\dagger=\Psi_H{}^*$. For an observable $\Omega=\Omega^\dagger$ we interpret Ψ_H as a probability distribution for eigenvalues of $(^\circ\eta{}^H\Omega)$, but the energy can be given by the Hamiltonian in Heisenberg representation $^H\mathcal{H}$ itself $(={}^\circ\mathcal{H}_0)$, or $^H\mathcal{H}_0$ in zeroth-order approximation, with the perturbation causing the electron self-energy $\delta\mathcal{E}$. We thus find[2] $\delta\mathcal{E}=m_ec^2$ for Proca quantum mass $m_\pi\approx10^{125}m_e$, and $\delta\mathcal{E}\approx0.02\ m_ec^2$ for $m_\pi=274\ m_e$, for which m_π. Bopp's classical theory gave $\delta\mathcal{E}=m_ec^2$.

[1] F. J. Belinfante, Abstract I9, Chicago meeting Am. Phys. Soc., October, 1951.
[2] A. Pais, Koninkl. Nederland. Akad. Wetenschap. Verh. (1e Sectie), **19**, 1 (1947), particularly pp. 59–60.

I9. On the Definition of the Integral over Paths in Feynman's Formulation of Nonrelativistic Quantum Mechanics. W. H. Guier* and A. J. F. Siegert, *Northwestern University.*—Feynman[1] defines his integral over all paths $x(t)$ by dividing the time interval t_2-t_1, into small intervals $\Delta t=t_{k+1}-t_k$ and integrating over the variables $x_k\equiv x(t_k)$, with the specification that, inside each interval, $x(t)$ is the path followed by a classical particle between x_k, t_k and x_{k+1}, t_{k+1}. The division of the time interval and the introduction of the classical path into the definition of the integration in function space can be avoided by using the averaging process of random function theory, defining

$$K(x_1,t_1|x_2,t_2)=\langle\chi\{\eta(t);t_1,t_2\}\delta(x_2-x_2-\int_{t_1}^{t_2}\eta(t)dt)\rangle_{\text{Av}}.$$

$\chi\{\eta(t);t_1,t_2\}$ is a functional of $\eta(t)$ and a function of t_1 and t_2, and the average over functions $\eta(t)$ is defined by giving the averages of products $\eta(t_1)\eta(t_2)\cdots\eta(t_n)$ as specified in reference 2, Eqs. (41a, b); 42a, b) with $D=i\hbar/2m$, where m is the mass of the particle.

* Now at The Johns Hopkins Applied Physics Laboratory, Silver Spring, Maryland.
[1] R. P. Feynman, Revs. Modern Phys. **20**, 367 (1948).
[2] M. C. Wang and G. E. Uhlenbeck, Revs. Modern Phys. **17**, 323 (1945).

I10. Distribution of the Total Momentum of the Electrons in Pair Production by Photons. A. Borsellino, *Cornell University.*—The distribution of the total momentum $\eta=|\vec{p}_++\vec{p}_-|$ of the electrons in pair production by photons on an atom has been calculated in the two limiting cases of a bare nucleus and of complete screening. At high energies the distribution depends only on the quantity $Q^2=\kappa^2-\eta^2$ (where $\kappa=E_++E_-$), which is easy to obtain from measurements of the energies E_+, E_- and the angle ω between the electron and positron. The formulas may be useful in studying, independently of the direction of the photon, the recoil momentum of the nuclei and the distribution of the angle ω. Such an expression, independent of the direction of the primary, is particularly useful in the case of cosmic-ray photons.

I11. Nonlocal Photons. J. S. Lomont, *North American Aviation, Inc.*—Bloch has pointed out that zero rest mass photons must be local; however, the concept of "heavy photon" (finite rest mass) recently developed by several authors (e.g., Coester) suggests the possibility of a nonlocal heavy photon field. The Fourier expansion of the heavy free-photon potential $A_\mu(X)$ can be obtained by replacing $|\mathbf{k}|$ by $(|\mathbf{k}|^2+\kappa^2)^{\frac{1}{2}}$ in appropriate places in the expansion of the ordinary photon field. The expansion of the nonlocal potential satisfying the usual nonlocal equations can then be obtained by appropriately inserting delta functions containing r in the local heavy photon potential expansion. The nonlocal commutation relations reduce to the local relations as $\lambda\rightarrow0$ if $A_\mu(X,r)$ is properly normalized. The total nonlocal Hamiltonian is the same as the local Hamiltonian so nonlocal photons have the same statistics as local photons. The nonlocal photon field interacting with an electron field can then be quantized by the method of "direct quantization" (extension of the Yang-Feldman theory) with the aid of an appropriate nonlocal delta-function. However, the interacting field can be quantized in accordance with either the correspondence principle or the reciprocity principle, so there is some ambiguity.

I12. Subtractive Bosons in a Generalized Theory. Alex E. S. Green, *The University of Cincinnati.*—In a generalized field theory based upon a higher order quadratic Lagrangian, alternate bosons make negative contributions to the total field energy.[1,2] The purpose of this paper is to investigate the possibility that the total field energy will nevertheless be positive definite. We first consider the use of supplementary conditions somewhat analogous to those used in ordinary electrodynamics to suppress negative total energy states. Although suitable for the empty field, this approach appears to lead to difficulties when sources are present. We next consider the use of a perturbation procedure, involving a generalization of the usual occupation number operator concept, which automatically imposes mild restrictions upon the field eigen states. This more natural approach seems quite promising in several respects. It casts suspicion upon the assumption which has been made in many articles that the various mass components of a generalized field are completely independent. A great many problems remain to be considered, in particular the problem of quantizing the source field and the problem of relating such a mathematical description to the confusing experimental observations.

[1] A. Green, Phys. Rev. **73**, 26, 519 (1948); **75**, 1926 (1949).
[2] A. Pais and G. E. Uhlenbeck, Phys. Rev. **79**, 145 (1950).

I13. Operators and Field Theories.* James L. Anderson, *Syracuse University*.—A mathematically rigorous treatment of certain quantum-field-theoretical problems may be achieved with the help of normal-mode representation, which converts the problem into one with a denumerable number of degrees of freedom. Such a decomposition is, however, not readily available in a covariant nonlinear theory, in which the Hamiltonian contains higher than second-degree terms. In any case, an operator is properly defined if it transforms one Hilbert vector into another one. In an attempt to discover approaches circumventing normal modes, we have treated the uniform string of finite length and have cast the Hamiltonian with vanishing zero-point energy into a form free of Fourier coefficients. When we constructed other operators, it was found that only when the corresponding classical variable is the generating functional of a nonsingular canonical transformation, will the quantum analog be a "good" operator. Though this condition obviously is not sufficient, it may be that any operator satisfying it can be turned into a "good" operator merely by the reordering of factors.

* Supported by ONR.

I14. Lower Limits for Interaction Times in Elementary Particle Processes. E. Gora, *Providence College* (Introduced by R. B. Lindsay).—A lower limit for the duration of the interaction between a photon and a charged particle has been obtained in a semiclassical way by assuming correspondence between the photon and a classical wave train of finite length. For spinless particles obeying the equations of motion of Dirac's classical theory of the electron, and photon energies $\hbar\omega \gg mc^2$ (m mass of the scattering particle) this lower limit is $\tau_0(\hbar\omega/mc^2)$ where $\tau_0 = \hbar^2/16me^2c$. This expression resembles formulas for lifetimes of unstable particles both in its dependence upon fundamental constants and in its increase with the energy involved in the process. The transfer of linear momentum to the scattering particle appears to be essentially due to radiation reaction in such a semiclassical theory.[1] An attempt is now made to link these results up with the quantum theory of radiation damping. Different types of interaction processes between elementary particles are taken into consideration.

[1] E. Gora, Phys. Rev. **84**, 1119 (1951).

Thursday Afternoon at 2:15

Havemeyer 309

(R. Smoluchowski presiding)

Metals and Magnetism

J1. On the Activation Energy for Grain Boundary Viscosity in Metals. A. S. Nowick, *Yale University*.—The proposal by Kê,[1] that the activation energy for grain boundary viscous slip may be identical with the activation energy for volume diffusion, has aroused much attention. This proposal is based upon very little experimental evidence, nor has there been, as yet, any theoretical justification for it. Recent experiments make possible a direct comparison of the two activation energies in binary alloys which show anelastic effects caused by stress-induced atomic reorientation.[2] For such an alloy a plot of internal friction *versus* temperature shows a double peak. The low temperature peak is a result of the stress-induced reorientation and is therefore controlled by diffusion; the high temperature peak results from grain boundary viscous slip. From the change in resolution of the two peaks with a change in vibration frequency, it is possible to detect small differences in the activation energies for the two processes. Results in α-Ag-Zn and α-brass alloys show that the activation energy for viscous slip is consistently about ten percent *greater* than that for volume diffusion. This result implies that the mechanisms for the two processes are not the same. A tentative mechanism for grain boundary slip is suggested.

[1] T. S. Kê, Phys. Rev. **73**, 267 (1948).
[2] C. Zener, Phys. Rev. **71**, 34 (1947); A. S. Nowick, Phys. Rev. **82**, 340(A) (1951).

J2. Mechanical Properties of Thin Films of Silver.* W. E. Walker, T. J. Turner,† and J. W. Beams, *University of Virginia*.—Films of silver of uniform thickness were deposited on small cylindrical steel rotors with rounded ends, and the rotational speeds required to throw them off of the rotors were measured. The films were deposited on the rotors either by electroplating or by evaporation. The rotors were spun in a high vacuum by a method previously described.[1] If N is the rotor speed required to throw off the film, R the radius of the rotor, T the tensile strength, A the adhesion, d the density, and h the thickness of the silver film, then $4\pi^2 dN^2R^2 = T + (AR/h)$. By using rotors of different diameters, both the tensile strength and the adhesion of the films were determined as a function of the thickness. The tensile strength increased markedly as the film thickness was decreased from 10^{-4} to 10^{-5} inch. The adhesion to the rotor was a function of the process of deposition.

* This work was supported by U. S. Navy Bureau of Ordnance under Contract NOrd-7873.
† Now at the University of New Hampshire.
[1] Beams, Young, III, and Moore, J. Appl. Phys. **17**, 886 (1946).

J3. Relations between Thermal Expansion and Chemical Composition of Some Binary Aluminum Alloys. Peter Hidnert, *National Bureau of Standards*.—Relations between the coefficients of linear thermal expansion and the chemical composition of annealed aluminum-beryllium (about 10 to 70 atomic percent beryllium), aluminum-copper (1 to 18 atomic percent copper), and of aluminum-silicon (5 to 40 atomic percent silicon) alloys were obtained. The relations were derived from data obtained on the coefficients of expansion of these annealed alloys for several temperature ranges between 20° and 300°C. The addition of beryllium, copper, or silicon to aluminum causes a decrease in the coefficients of expansion. The relations between the coefficients of expansion of these eutectiferous alloys and the chemical composition (atomic percent) are approximately linear, and are therefore in agreement with the theory for the eutectiferous portions of the equilibrium diagrams of the binary alloys. Copper has a greater effect than beryllium, and silicon has the greatest effect of these three alloying elements. The data on these binary alloys will be published in the *Journal of Research* of the National Bureau of Standards.

J4. Influence of Stress on the Temperature of the Diffusionless Transformation in Au–Cd Single Crystals.* J. INTRATER, L. C. CHANG, AND T. A. READ, *Columbia University*.—In the neighborhood of 60°C the alloy of gold containing 47.5 at. % cadmium undergoes a first-order phase change from a high temperature CsCl structure to an orthorhombic structure. The transformation occurs by a shear mechanism, which leads to a change in shape of the sample, with a temperature hysteresis of about 10°C between heating and cooling.[1] In the present work it has been found that an applied shear stress produces a linear shift of the two transformation temperatures, without changing the difference between them. Thus the measured shift is probably equal to that of the thermodynamic equilibrium temperature for the two phases. On this assumption the latent heat of transformation has been calculated from the measured transformation strain and the rate of change of transformation temperature with stress, with the Clausius-Clapeyron equation. A value of 0.40 calories per gram is obtained. This value is now being checked by calorimetric measurements.

* This work was supported by the AEC.
[1] L. C. Chang and T. A. Read, Trans. Am. Inst. Mining Met. Engrs. **189**, 47 (1951).

J5. Grain Boundary Diffusion of Zinc in Copper.* R. SMOLUCHOWSKI AND R. FLANNAGAN, *Carnegie Institute of Technology*.—The depth of penetration of zinc along grain boundaries of columnar copper has been measured as a function of the angle between the two grains. Similarly to the earlier results on diffusion of silver along grain boundaries of columnar copper, the depth of penetration along grain boundaries is greater than volume penetration only for angles greater than about 20° and reaches a maximum at 45°. This critical angle increases with increasing temperature of diffusion in accord with the known fact that at sufficiently high temperatures only volume diffusion is observed. The activation energies have been measured and their dependence on the angle indicates a significant change in the permeability of the grain boundary at the critical angle. These results are in accord with the previously proposed model.[1]

* Sponsored by an AEC contract.
[1] M. R. Achter and R. Smoluchowski, J. Appl. Phys. **22**, 1260 (1951).

J6. Strain Rate, Temperature, and Time Effects in the Ballistic-Speed Deformation of Mild Steel. J. M. KRAFFT, *Naval Research Laboratory*.—Continuous force-time records of the penetration of conical projectiles were obtained from the moving strain pattern introduced into a Hopkinson bar by measuring the strain as a function of time with wire-resistance gages. Penetrations on a fully annealed, low carbon steel have been made with 45° cones at impact velocities ranging from 600 to 2200 ft/sec at temperatures ranging from $-100°C$ to $+75°C$. The results show that in the strain rate range of 10^4 to 10^5 sec^{-1}, the cone penetration resistance increases linearly with the strain rate at 0.5 lbs/in.^{2}/sec^{-1}. At constant strain rate the penetration resistance decreases linearly with increasing temperature at the rate of 680 lbs/in.^{2}/°C. There is an indication of a "delay time" for plastic yielding of about four microseconds associated with these cone impacts.

J7. Effect of Grain Size on Magnetoresistance of Polycrystalline Copper.* GEORGE B. YNTEMA, *Yale University*.—The magnetoresistance of three samples of copper was measured at liquid helium temperatures, and was found to depend on the grain size of the sample. Such dependence was suggested by MacDonald.[1] The ratio of resistance increment in a magnetic field to the resistance in zero field was 3.5 times as large in the sample with smallest crystal size as in that with the largest crystals. The zero field resistance of the former sample was 0.44 times that of the latter. Samples were wire drawn from Hilger spec-pure copper. The wire was annealed, then cold worked by bending and reannealed to obtain random crystal orientation. The grain size was controlled by the temperature of the second anneal. Similar work is being carried out on other metals.

* Assisted by an AEC Predoctoral Fellowship.
[1] D. K. C. MacDonald, Phil. Mag. **42**, 756 (1951).

J8. Hall Effect in Zinc Crystals at Low Temperatures. JOHN K. LOGAN,* *Northwestern University*.—An experimental study has been made of the Hall effect in single crystals of zinc. For each crystal, one component of the Hall field was measured for a fixed crystallographic orientation of the current density, but for various orientations of the magnetic field in the plane perpendicular to the current density. At 77°K, the Hall field is a linear function of magnetic field which can be characterized by two coefficients. The first coefficient, for the interaction between the field component parallel to the hexagonal axis and current density component in the hexagonal plane, has a value of about 2×10^{-12} ohm cm/gauss. The second coefficient measures the interaction between the field component in the hexagonal plane and the current density component perpendicular to this field component. Its value is about 0.2×10^{-12} ohm cm/gauss. At 20.4°K, the Hall field is no longer linear with magnetic field. For some orientations, the measured component of the Hall field increased with increasing magnetic field. In other cases, the opposite behavior was observed. Between 5 and 10 kilogauss, the Hall effect is of the same order of magnitude at 20.4°K as at 77°K. No correlation was apparent between the Hall effect and either susceptibility or magnetoresistance.

* An AEC Predoctoral Fellow. Now at Naval Research Laboratory.

J9. Multiple Scattering of μ-Mesons in Magnetized Iron. STEPHAN BERKO, *University of Virginia* (introduced by Frank L. Hereford).—Previous experiments[1] on the deflection of μ-mesons in iron employed computed corrections for multiple scattering. The importance of scattering in such experiments has since been discussed theoretically.[2] In the experiment to be described, a beam of μ-mesons was made to penetrate 15 cm of iron, and the angular distribution as a result of multiple scattering was observed with a set of 12 counters located 80 cm below the iron block. Each of these counters was in coincidence with the collimating telescope above the iron. The multiple scattering curve with the iron unmagnetized fitted the theoretical one if the known momentum distribution was assumed. The distribution curve with the iron magnetized was then observed and the two curves compared. The observed effect agrees with the assumption that B is the effective vector inside the ferromagnetic medium. The assymmetry introduced by the magnetic field demonstrates the positive excess of μ-mesons. With increased resolution one will be able to deduce the relative momentum distribution of positive *vs* negative mesons.

[1] W. F. G. Swann and Danforth, Phys. Rev. **45**, 565 (1934); F. Rasetti, Phys. Rev. **66**, 1 (1944); Bernardini, *et al.*, Phys. Rev. **68**, 109 (1945).
[2] G. Wannier, Phys. Rev. **72**, 304 (1947).

J10. A Theory of Intrinsic Magnetization in Alloys. W. J. CARR.—The intrinsic magnetization of alloys among the iron transition group of metals has been explained using a Heitler-London model for the *3d* electrons. The magnetic moment associated with each atom is determined by the principle of maximum spin and the sign of the interaction between neighboring pairs from the overlap of the wave functions. It is found that a large number of alloys derive their spontaneous magnetization from an antiparallel arrangement of atomic spins.

J11. Collective Electron Theory of the Saturation Moment of Alloys. J. E. GOLDMAN, *Carnegie Institute of Technology.*—The influence of alloying on the saturation magnetic moment is treated from the collective electron standpoint in a manner analogous to Slater's and James' treatment of impurities in a semiconductor.[1] The method is based on the local distortions in the density of states of an energy band caused by a perturbation in the periodic potential. It is shown that where the solute atom is one that differs from the matrix atom by several atomic numbers (as, for example, chromium in nickel), this perturbation has the effect of causing the occupancy probability for some of the states at the bottom of the *3d*-band to become very small. Thus some electrons must go into states of higher Fermi energy, but in the *3d*-band of a ferromagnetic metal the only states available such as these are of negative spin. The net effect is to decrease the magnetic moment of the material provided the perturbation energy is larger than the exchange energy. This suggests a means of explaining the deviations from Pauling's curve in certain alloy systems[2] that differs from the Heitler-London-Neel approach previously proposed.[3]

[1] J. C. Slater, Phys. Rev. **76**, 1592 (1949); H. M. James, Phys. Rev. **76**, 1602 (1949).
[2] R. M. Bozorth, Phys. Rev. **79**, 887 (1950).
[3] J. E. Goldman, J. Appl. Phys. **20**, 1131 (1949).

J12. Domain Structure of Perminvar with a Rectangular Hysteresis Loop. H. J. WILLIAMS AND MATILDA GOERTZ, *Bell Telephone Laboratories.*—Domain patterns obtained with colloidal magnetite on polycrystalline rings of perminvar (43 percent Ni, 34 percent Fe, 23 percent Co), having rectangular hysteresis loops after heat treatment in a magnetic field,[1] showed circular domain boundaries concentric with the rings. An applied magnetic field caused the domain boundaries to either expand or contract so that the relative value of the clockwise and counterclockwise flux circuits changed thus varying the net flux. Nuclei of reversed magnetization were formed by making small notches in the specimens which decreased the coercive force and hysteresis loss by a factor of two. It was found that the change in spin orientations in crossing a 180° domain boundary could be made to have either a right- or left-hand screw relation by the application of a magnetic field of appropriate sign perpendicular to the surface.

[1] J. F. Dillinger and R. M. Bozorth, Physics, 279 (1935).

J13. Neutron Diffraction Studies of Various Transition Elements. C. G. SHULL AND M. K. WILKINSON, *Oak Ridge National Laboratory.*—Powder diffraction patterns have been taken for a series of transition elements, V, Cr, Mn, Cb, Mo, and W in order to establish the presence of possible magnetic structure and to determine the strength of the localized atomic magnetic moments. V, Cb, and W exhibit no observable magnetic scattering effects, either coherent or incoherent, and, hence, from the sensitivity of observation an upper limit of $0.1\mu_B$ for V and $0.3\mu_B$ for W can be set for the maximum strength of the atomic moments, either aligned or unaligned. These materials were studied at temperatures as low as 20°K. Cr, on the other hand, exhibits an antiferromagnetic structure with Curie temperature about 150°C and with an atomic moment of $0\,40\mu_B$. From the absence of magnetic diffuse scattering in Cr at low temperatures, a maximum strength of $01.\mu_B$ can be set for any unaligned moments. The absence of a magnetic moment in V and the presence of a weak moment in Cr agrees rather well with the Slater-Pauling-Shockley curve of magnetic moment *versus* electron concentration when this is extrapolated into the nonferromagnetic region. Studies on Mn are in progress and will be reported.

J14. The Magnetic Properties of the Chromites. W. G. SCHINDLER, T. R. MCGUIRE, LOUIS N. HOWARD, AND J. SAMUEL SMART, *U. S. Naval Ordnance Laboratory.*—The chromites are a series of compounds with the chemical formula MCr_2O_4 where M is a divalent metallic ion. They have the same crystal structure (spinel) and about the same size unit cell as the ferrites.[1] Magnetic susceptibilities over the temperature range 77°K to 1300°K have been measured. The susceptibility curves for Mg and Zn chromites obey a Curie-Weiss law with a negative θ, indicating a negative exchange interaction between magnetic atoms on the octahedral sites. For Mn, Co, Ni, and Cu chromites, the $1/\chi$ *versus* T curve can be represented by a Néel hyperbola.[2] Co and Cu chromites become ferromagnetic at 110°K and 135°K respectively, while Mn and Ni chromites become ferromagnetic somewhere below 77°K. The saturation magnetizations at 4.2°K and 7400 gauss were measured using a ballistic method. Saturation values in Bohr magnetons (μ_B) per molecule are Mn chromite, $1.5\mu_B$; Co chromite, $0.2\mu_B$; Ni chromite, $0.3\mu_B$; and Cu chromite, $0.7\mu_B$. A discussion of the experimental results of this investigation with relation to the Néel theory will be given.

[1] J. W. Verwey and E. L. Heilmann, J. Chem. Phys. **15**, 174 (1947).
[2] L. Néel, Ann. phys. **3**, 137 (1948).

J15. Temperature Dependence of the Magnetic Spectrum of a Ferrite. G. T. RADO, R. W. WRIGHT, W. H. EMERSON, AND A. TERRIS, *Naval Research Laboratory.*—The two natural ferromagnetic resonances previously studied[1] at room temperature have now been observed at 411°K, 195°K, and 77°K in the same sintered material. As the temperature decreases over this range, the mean resonance frequencies ω_0' and ω_0'', which are measured at the absorption peaks and attributed to domain rotations and wall displacements, respectively, both increase by about 500 percent; the total static initial susceptibility, $\chi_0=\chi_0'+\chi_0''$, decreases substantially; and the two "line" widths change in a complicated way because of partial overlapping. By using single-domain particles of this material embedded in wax, the rotational resonance was observed separately, and χ_0', the rotational static initial susceptibility, found to be independent of temperature below 300°K. By assuming that domain rotations *and* wall displacements are, in this material, determined primarily by crystalline anisotropy and demagnetizing fields rather than by internal stresses, and that (as in molecular field theory) the exchange energy varies as the square of the saturation magnetization, it is shown theoretically that ω_0'/ω_0'' is independent of temperature whenever χ_0' is independent of temperature. This relation is unaffected by the Landé g factor and agrees satisfactorily with the measurements.

[1] Rado, Wright, and Emerson, Phys. Rev. **80**, 273 (1950).

THURSDAY AFTERNOON AT 2:15

McMillin

(G. E. MOORE presiding)

Invited Papers in Electron Physics

K1. Progress in Gaseous Electronics: Report on the Conference of October 1951. W. P. ALLIS, *M.I.T.* (50 min.)

K2. Progress in Electron Physics: Report on the NBS Electron-physics Symposium. L. MARTON, *National Bureau of Standards.* (50 min.)

K3. Surface and Volume Recombination in Germanium. R. N. HALL, *General Electric Company.* (30 min.)

THURSDAY AFTERNOON AT 2:15

Pupin 428

(J. H. MCMILLEN presiding)

Fluid Dynamics

L1. Spalling Produced by Detonation of Explosives in Very Heavy Walled Metal Tubes. L. STARR AND J. SAVITT, *U. S. Naval Ordnance Laboratory.*—In experiments with small, highly confined explosives, it was noted that under some conditions a conical slug of metal was torn from the free end of the metal container. After some speculation, this phenomenon was explained in terms of the convergence of tension waves which had been reflected from free surfaces. Experiments, in which explosives were used and the geometry of the containers were varied, confirm the explanation.

L2. Approximate Analytic Solutions in the Problem of a Spherical Blast. J. A. MCFADDEN, *U. S. Naval Ordnance Laboratory.*—A sphere containing a perfect gas at uniformly high pressure is allowed to expand suddenly into a homogeneous atmosphere. Solutions for short times later are sought by analytic (i.e., not numerical) means. Viscosity and heat conduction are neglected; the particle velocity, sound speed, and entropy are developed in powers of the time, the coefficients depending principally on a slope coordinate $q=(x-R)/t$, where x is the radial coordinate and R is the radius of the original gaseous sphere. (This expansion was also used by Wecken.[1]) The zero-order solution is the plane-wave (shock-tube) solution. The rarefaction zone was discussed in an earlier paper;[2] here the method is extended to the regions between the rarefaction and the outgoing shock. The first-order coefficients are linear in q and also depend weakly on t itself; the pressure is constant spacewise but decreases with time. In the region between the gas-air interface and the outgoing shock, numerical results are given for $\gamma=1.4$, an initial pressure ratio of 13, and a density ratio of 4.

[1] Wecken, Z. angew. Math. Mech. 30, 270 (1950).
[2] J. A. McFadden, Phys. Rev. 84, 611 (1951).

L3. Hypersonic Viscous Flow Over a Flat Plate.* L. LEES AND R. F. PROBSTEIN, *Princeton University.*—The steady hypersonic flow of a viscous, heat conducting gas over a semi-infinite flat plate is examined in a region away from the leading edge. As a result of the curvature of the relatively thick boundary layer, variations in pressure are propagated into the main stream along Mach lines, with a subsequent interaction between the "inviscid" field and the boundary layer growth. Solution of this problem shows that the important generating parameter is $M^3/(Re_x)^{\frac{1}{2}}$, where, M is the free stream Mach number and Re_x the Reynolds number based on distance from the leading edge. By successive iterations between the "internal" and "external" fields, asymptotic expansions in terms of $M^3/(Re_x)^{\frac{1}{2}}$ are found for the flow quantities such as pressure, velocity, temperature, etc. The zero-pressure gradient flat-plate boundary layer solution is the first approximation in the expansions. It is shown that there is a wedge-like domain where the "higher order" viscous terms in the x-momentum equation can be neglected. In addition to the horizontal pressure gradient, the gradient normal to the plate is evaluated. From the results, the region of validity of the zero pressure gradient boundary layer solution, as well as the error made in the skin friction and heat transfer rate determined by this solution, can be found. When $M^3/(Re_x)^{\frac{1}{2}}$ is not small, compared to one, the error is considerable.

* This work was supported by the United States Air Force, Air Materiel Command.

L4. Transonic Flow Past a Wedge at Zero Angle of Attack. LEON TRILLING, *Massachusetts Institute of Technology* (Introduced by H. G. Stever).—The steady plane flow of an ideal inviscid nonconducting gas past a thin symmetric diamond wedge at zero angle of attack was investigated theoretically at speeds just below the velocity of sound. The problem was studied in the hodograph plane where the coordinate $y(u, v)$ is a solution of the Tricomi equation, and $x(u, v)$ satisfies a similar equation. The boundary conditions require $y(u, v)$ to have a branch-point singularity $y\sim 1/(u-u_1)^{\frac{1}{2}}$ where u_1 is the free stream velocity; y vanishes along both sides of the cut extended from $u=u_1$ to $u\rightarrow-\infty$; along the straight lines $v=\pm v_0$ which represent the wedge surface, and along the downward characteristic through $(0, +v_0)$; forward and rear stagnation points are defined by the condition $\lim_{u\rightarrow-\infty} x(u, \pm v)=\pm c$. A solution approximately satisfying these conditions and depending only on the transonic similarity parameter ξ_0 was constructed. The flow was found to be subsonic up to the corner; sonic at the corner, where a local Prandtl Meyer over-expansion followed by a weak oblique shock took place. There followed a decelerating supersonic flow, ending in a normal shock some distance ahead of the rear stagnation point. The pressure drag, the location, and the strength of the shocks were computed for several values of ξ_0.

L5. On the Recent Development in the Turbulence Theory in Compressible Fluids. M. Z. v. KRZYWOBLOCKI, *University of Illinois* (Introduced by Charles Fletcher).—In his previous paper the author derived the generalized fundamental equations of an isotropic, homogeneous turbulence in compressible viscious fluids. This may be considered to be a generalization of Kármán-Howarth theory. In the present paper the author presents a generalized theory of locally isotropic turbulence which may be considered to be a generalization of Kollmogoroff's theory. Two generalized similarity hypotheses are presented, as well as the conclusions that are derived from these hypotheses.

L6. An Experimental Model of Turbulence.* ROBERT BETCHOV, *University of Maryland*.—An electronic resonant circuit has been built, containing in addition to the usual elements (resistance, capacity and self induction), a particular nonlinear element. When this circuit is excited by a random noise, it responds with another random signal, and in addition, with occasional transients (intermittent pulses). These transients are excited by the random motion, but they correspond to particular trajectories in a suitable phase space. A comparison with real aerodynamical flows showed that in some cases the velocity fluctuation can be considered as the sum of a random signal and of excited transients, corresponding to certain phase trajectories. The basic equation of this nonlinear circuit is somewhat similar to a one-dimensional momentum equation of Navier-Stokes types and the significant parameter could be interpreted in terms of fluid dynamics.

* This work is supported by OAR.

L7. Free-Flight Determination of the Boundary Layer Transition on Cone Cylinders. W. R. WITT, JR., *U. S. Naval Ordnance Laboratory* (Introduced by Albert May).—Investigations are being made to determine the effect of various factors on the transition of the boundary layer from laminar to turbulent flow. At the present time one of the greatest uncertainties in the prediction of skin temperature, skin-friction drag, and base-pressure drag of supersonic missiles is whether the boundary layer is laminar or turbulent. The position of boundary layer transition cannot now be predicted accurately, since it is influenced by a variety of factors such as Mach number, surface roughness, surface temperature, pressure gradient, free-stream turbulence, and surface curvature. The quantitative effect of these factors, either singularly or interrelated is not known. Approximately 35 shots have been analyzed. The models were 20 mm, 25-degree cone cylinders. They were fired in a pressurized ballistics range which is equipped with shadowgraph stations. The transition regions were determined from the appearance of turbulence on the shadowgraph plates. Two degrees of surface finish were employed on different cones. On one group the cone finish was 4- to 10-micro inches and on the other the finish was 35- to 50-micro inches. The boundary layer transition occurred approximately one-half inch nearer the tip of the cones on the rougher models.

L8. Explicit Construction of Large-Amplitude Water Waves in Channels. R. P. SHAW.—A method is given for the construction of the general solution (involving two arbitrary functions) of any homogeneous system of partial differential equations where the coefficients depend only on the two dependent or on the two independent variables. Use is made of an operator involving contour integration, usually around branch points of a Riemann surface. An indication of the utility of the method, as well as some of the difficulties to be expected, is shown in an application to the equations resulting from a hodograph transformation of the equations governing the adiabatic flow of a compressible polytropic fluid with arbitrary adiabatic exponent γ, particularly to the case $\gamma=2$, corresponding to large amplitude water waves in channels. For this case the operator is inverted to give explicit formulas for waves satisfying arbitrarily prescribed initial conditions.

L9. A Preliminary Investigation of a Shock Wave Turbulent Boundary Layer Interaction. S. M. BOGDONOFF AND A. H. SOLARSKI, *Princeton University*.—Preliminary data in the form of static and pitot pressure distributions and shadow and schlieren photographs have been obtained for the interaction of a pressure ratio 2.09 shock wave with a turbulent boundary layer on a flat wall at $M=2.97$. Separation of the boundary layer appears to be incipient and a model of the interaction has been constructed. The model compares closely with that of Bardsley and Mair for turbulent layer-medium strength shocks and resembles as well that obtained by Leipmann for the interaction of weak shocks at low Mach numbers with a laminar layer. Longitudinal static pressure distributions show an upstream influence of approximately three boundary layer thicknesses with an inflection in the curve characteristic of laminar interactions. The entire pressure rise occupies six boundary layer thicknesses and agrees satisfactorily with the theoretically predicted rise. Velocity profiles in the region of the steepest pressure rise, i.e., slightly ahead of the point of impingement of the incident shock, show a behavior that may be associated with imminent separation.

L10. On Shock-Wave Phenomena: Aerothermodynamic Interaction. H. POLACHEK AND R. J. SEEGER, *U. S. Naval Ordnance Laboratory*.—Shock waves accompanied by a gain (or loss) of energy from an external source are a frequent occurrence in nature. A detonation wave is an illustration of such a phenomenon. Another example is a condensation wave, often observed in wind tunnels at high Mach numbers. It is possible to study the resultant equilibrium effects of addition or subtraction of energy immediately behind such shock fronts without detailed information as to the mechanism of the physical process. In the present paper an exploratory numerical analysis has been made of the characteristics of configurations that may result from the interaction of two shock waves of the type described above.

L11. One-Dimensional Theory of Absorption and Amplification of a Plane Shock Wave by a Gaseous Layer. D. BITONDO, I. I. GLASS, AND G. N. PATTERSON, *University of Toronto*.—The problem of gaseous refraction of a plane shock wave at a contact surface is applied to the case where the incident shock wave must pass through a finite layer of gas. Thc resulting wave system after refraction at a contact surface depends on the ratio of internal energies separated by the contact surface. When the ratio of the internal energies is greater than a certain minimum value, then the resulting wave system is a transmitted shock wave of lower strength than the incident shock wave, and a reflected rarefaction wave. When the internal energy ratio is less than a certain maximum value, then the transmitted shock wave is of higher strength and a shock wave is reflected. In the layer problem, the incident shock wave is refracted at two contact surfaces in succession, and when the emergent shock wave is of a lower strength than the original incident shock wave, then absorption is said to occur. The theory is applied to the practical case where the layer contains a gas which is bounded by air at room temperature at both contact surfaces. Under these conditions the emergent shock wave is always partly absorbed. When the gas in the layer is hydrogen, very significant shock wave absorption occurs even when the hydrogen is at room temperature.

FRIDAY MORNING AT 10:00

Horace Mann Auditorium

(J. STEINBERGER presiding)

Production, Decay and Interactions of Pi-Mesons

M1. Production of Photomesons from Deuterium.* JAMES KECK AND RAPHAEL LITTAUER, *Cornell University*.—The reaction $\gamma+d\rightarrow\pi^-+p+p$ is being investigated by bombarding targets of D_2O and H_2O with bremsstrahlung from the Cornell 310-Mev electron synchrotron. π-mesons emitted at 90° are identified in a counter telescope by specific ionization and range and are counted in coincidence with protons emitted at approximately 30°. The energy and angular distributions of the protons are measured for a known meson energy. These parameters determine the energy of the photon and also the initial momentum of the neutron within the target nucleus. The background due to the oxygen is about 30 percent of the total count. The observed angular distribution of the protons is compatible with reasonable assumptions about the internal momentum of the deuteron. The cross section of the elastic interaction (that in which only one of the residual protons carries away momentum) has been found to be of the order of 10^{-29} cm² sterad⁻¹ at a photon energy of 220 Mev. This is comparable to the cross section for $\gamma+p\rightarrow\pi^++n$ at the same energy.[1]

* This work was performed under contract with the ONR.
[1] Bishop, Steinberger, and Cook, Phys. Rev. **80**, 291 (1950).

M2. Dependence of Charged Pion Production on Incident Proton Energy.* S. PASSMAN, M. M. BLOCK, AND W. W. HAVENS, JR., *Columbia University*.—The 90° differential cross section for production of charged pions has been measured for several elements at proton energies of 345, 365, and 380 Mev. The technique, utilizing nuclear emulsions as detectors for mesons produced in targets bombarded by the internal beam of the Nevis cyclotron, has been previously described.[1] The proton energy is varied by changing the distance of the target from the center of the cyclotron magnetic field. Preliminary results for the integrated 90° cross section for π^+ production in hydrogen (by subtraction of carbon from polyethylene) are $(d\sigma)/(d\omega)=(2.9\pm30\%)\times10^{-29}$ cm²/sterad for a proton energy of 345 Mev, and $(d\sigma)/(d\omega)=(3.9\pm30\%)\times10^{-29}$ cm²/sterad for a proton energy of 365 Mev. The total cross sections for meson production in hydrogen are calculated by assuming the reaction $P+P\rightarrow\pi^++D$ with a $\cos^2\theta$ angular dependence in the center-of-mass system.[2] Combined with the previously reported cross section for hydrogen at 381 Mev,[1] the ratios of the production cross sections are: (σ_{total} at 381 Mev):(σ_{total} at 365 Mev):(σ_{total} at 345 Mev)$=2.1:1.6:1$.

* This research was assisted by the joint program of the AEC and ONR.
[1] Block, Passman, and Havens, Jr., Phys. Rev. **83**, 167 (1951).
[2] Peterson, Iloff, and Sherman, UCRL-1405 (1951); Cartwright, Richman, Whitehead, and Wilcox, UCRL-1278 (1951).

M3. Photoproduction of Mesons on Nuclei. T. R. PALFREY, JR., AND R. R. WILSON, *Cornell University*.*—We are measuring the relative differential meson energy cross sections for the photoproduction of charged mesons from various targets. Preliminary results have been obtained for mesons of energy 40–80 Mev produced from C and Pb at 135° to the 310-Mev synchrotron brehmsstrahlung gamma-ray beam. The detector is a scintillation counter telescope of one NaI(Tl) crystal and one terphenyl-xylene liquid scintillator, each 10 cm in diameter and 1 cm thick. Mesons are identified by their pulse height in the second (NaI) crystal. Their charge and momenta are determined by the magnet system of Camac, *et al.*,[1] use of which also helps minimize corrections for nuclear interaction of the mesons in absorbers. The decay in flight correction is made theoretically, with the aid of a range-measurement estimate of the mu-meson contamination. Work is in progress on other targets. An inhomogeneous 90° sector magnet of the betatron type, with $n=\frac{1}{2}$, is being constructed. After calibration it should permit measurement of absolute cross sections at variable angles and at lower meson energies.

* Work supported by ONR.
[1] Camac, Corson, Littauer, Shapiro, Silverman, Wilson, and Woodward, Phys. Rev. **82**, 745 (1951).

M4. Relative Production of Neutral Mesons by 310-Mev γ-Rays in Hydrogen and Deuterium. A. SILVERMAN AND G. COCCONI, *Cornell University*.—The neutral mesons produced in various targets by 310-Mev bremsstrahlung radiation were detected by observing one of the decay gamma-rays at 90° to the primary beam. This method increases the counting rate by at least a factor of 10 in comparison to detecting the two decay γ-rays in coincidence. This is done at the expense of information concerning the angular distribution. The observed counts have the following characteristics: (a) they are due to γ-rays of energy greater than 40 Mev, (b) the threshold is approximately 150 Mev, (c) the excitation function, as determined by changing the maximum beam energy, is in reasonable agreement with published results for hydrogen,[1] (d) the observed rates correspond to those expected assuming the known cross sections for π^0 production.[1] The targets used were H_2O, D_2O, CH_2, and C. For γ-rays energies of about 300 Mev, the ratio of deuterium to hydrogen cross section for π^0 production is: $\sigma_D/\sigma_H=1.90\pm0.24$. This indicates that the cross sections for production of π^0 by γ-rays on neutrons and protons are approximately equal. The following relative cross sections have also been obtained: $\sigma_C/\sigma_H=10.1\pm1.8$, $\sigma_O/\sigma_H=12.7\pm2.5$.

[1] Panofsky, Steinberger, and Stellar, UCRL, 1495, October, 1951; A. Silverman and M. Stearns, Phys. Rev. **83**, 206 (1951).

M5. Production of 40-Mev π-Mesons by 240-Mev Protons in Seven Elements.* DONALD L. CLARK, *University of Rochester*.—The relative differential cross section for production of 40-Mev π^+ and π^- mesons by 240-Mev protons has been measured in Be, C, Al, Cu, Ag, W, and Pb. The π^+ mesons were observed in the angular range 130° to 150° with respect to the incident protons, and the π^- mesons in the range 30° to 50°. The relative cross section per nucleus was found to vary generally as the geometric cross section, but with significant departures for both positive and negative mesons. The departures from geometric cross section appear to correlate to some extent with the average binding energy per nucleon. The variation of the cross section for π^+ mesons differs significantly from that for π^- mesons. The ratio of the cross section for production of π^+ mesons to that for π^- mesons, at the angles indicated, varies qualitatively as the *a priori* ratio $A+Z/A-Z$ but considerably more strongly.

* This work was sponsored by the AEC.

M6. Measurement of the Production Cross Section of Negative Mesons in Carbon by 341-Mev Protons. WALTER F. DUDZIAK, *University of California, Berkeley*.—Meson production cross sections from carbon ($pC^{12}\rightarrow\pi^-$) in the forward direction to a 341-Mev incident proton-beam, have been measured. The produced charged mesons were magnetically separated and their number detected in Ilford C-2, (200μ) emulsions. The areas were scanned under 570 diameters magnification. The π^- spectrum is based on more than 450 observed star-forming π^- mesons. A comparison of the π^+ and π^- data shows surprising results which are in complete disagreement with those expected from the relation $\sigma^+/\sigma^- = (A+Z)/(A-Z)$ which results from the assumption that production matrices in $p-n$ and $p-p$ collisions are the same.[1] The peaks of the π^- and π^+ spectra occur at widely separated meson-energies. The σ^- peak occurs at $T_\pi < 25$ Mev, while the σ^+ peak occurs at $T_\pi > 70$ Mev. The σ^+/σ^- ratio of the peaks is approximately 15/1. Within experimental error the integral of the π^- spectrum over energies is the same as obtained at 90° to the proton-beam.[2] This is not true for the σ^+ integral. The marked decrease of σ^- with increasing meson-energy might be explained by the effect of the exclusion principle. The large increase of π^+ production may be the result of the resonance-reaction[3] which accompanies deuteron formation.

[1] E. M. Henley, UCRL-1467, September, 1951.
[2] C. Richman and H. Wilcox, Phys. Rev. **78**, 496 (1950).
[3] This idea has also been advanced by C. Richman.

M7. A Photographic Study of the Muon Range Spectrum from $\pi \rightarrow \mu$ Decay.* A. M. Seifert, H. J. Bramson, and W. W. Havens, Jr., *Columbia University*.—The search for anomalous muon ranges from $\pi \rightarrow \mu$ decay is being continued.[1] These abnormal muons have been previously reported[1,2] and have been interpreted to indicate a nonhomogeneous decay of the pion. Another interpretation may be the existence of an additional mechanism of energy loss of the muon, other than the usual energy loss by ionization.[3] A muon range spectrum is being compiled to clarify the nature of this anomaly. To date, some $3300 \pi \rightarrow \mu$ decays have been observed where the muon ends in electron sensitive emulsion. A total of six "short" muon decay ranges have been found with lengths: 235, 415, 440, 445, 470, and 485 microns, respectively. A preliminary spectrum of three hundred muon ranges exhibits the expected range straggling of 4–5 percent about the mean. At the low energy end, however, there is a definite indication of an extended non-Gaussian "tail." The shape of the spectrum, especially at the low energy end, is being further studied, and the results of increased statistics will be presented.

* This research is being assisted by the joint program of the ONR and AEC.
[1] Bramson, Seifert, and Havens, Jr., Bull. Am. Phys. Soc. **26**, No. 6, 23 (1951).
[2] W. F. Fry, Phys. Rev. **83**, 1268 (1951).
[3] H. Primakoff, private communication (to be published in Phys. Rev.).

M8. Scattering of Negative Pions by Hydrogen.* A. Lundby, E. Fermi, H. L. Anderson, D. E. Nagle, and G. Yodh, *University of Chicago*.—The scattering of negative pions of energy 115 Mev in liquid hydrogen has been studied using scintillation counter techniques. The beam incident in the hydrogen target is monitored by two 1-in.[2] scintillators in coincidence, spaced 10 inches apart. The scattering products are observed by quadruple coincidences of these with another pair of scintillators located directly under the scatterer at 90° from the incident beam direction. A $\frac{1}{4}$-in. Pb plate in front of the last pair was used to increase the sensitivity of the equipment to high energy gamma-rays. In a first experiment the ratio of scattered to incident particles without the Pb radiator was found to be $(0.81 \pm 0.05) \times 10^{-4}$ and $(1.21 \pm 0.08) \times 10^{-4}$ without and with liquid hydrogen in the scattering chamber, respectively. With the Pb radiator the corresponding numbers were $(0.71 \pm 0.06) \times 10^{-4}$ and $(1.73 \pm 0.09) \times 10^{-4}$. The net effects of the hydrogen with and without lead radiator are therefore $(0.40 \pm 0.10) \times 10^{-4}$ and $(1.01 \pm 0.11) \times 10^{-4}$. A large contribution because of high energy gamma-rays is apparent, and this is ascribed primarily to the charge exchange scattering with a small addition caused by radiative capture. These intensities are consistent with a total cross section of about 35×10^{-27} cm^2 as observed in the transmission experiments with the charge exchange scattering contribution two or three times as large as that of the ordinary scattering.

* Research supported by the ONR and AEC.

M9. Total Collision Cross Sections of Negative Pions on Protons.* D. E. Nagle, H. L. Anderson, E. Fermi, E. A. Long, and R. L. Martin,† *University of Chicago*.—The transmission of negative pions in liquid hydrogen has been measured using the pion beams of the Chicago synchrocyclotron. Pion beams with energies from 60 to 230 Mev were used. The transmissions were measured using scintillation counting techniques. The total collision cross section increases with energy starting from small values at 50 Mev and rising to the "geometrical" value of about 60×10^{-27} cm^2 at about 160 Mev. Thereafter, up to 220 Mev, the cross section remains close to this value. The steep energy dependence at low energies is consistent with interpretation that the pion is pseudoscalar with a pseudovector interaction.

* Research supported by the ONR and AEC.
† AEC Predoctoral Fellow.

M10. Difference of Hydrogen and Deuterium Total Cross Sections for Charged Pi-Mesons. G. Yodh, H. L. Anderson, D. E. Nagle, and H. Stadler, *University of Chicago*.—Transmission measurements in H_2O and D_2O are reported for negative pi-mesons at several energies. The experimental arrangement is similar to that reported by Martin, Anderson, and Yodh at this meeting. The results indicate that the total scattering cross section $(\sigma_D - \sigma_H)$ in the pion energy bands 92–116 Mev and 110–134 Mev is close to the geometrical value of 61 millibarns. In the energy band 41–58 Mev, $\sigma_D - \sigma_H$ has been measured less precisely, but appears to be much smaller.

M11. Slow π^- Meson Reactions in He^3. A. M. L. Messiah,* *University of Rochester*.—The pseudoscalar nature of the π^--meson has been established recently.[1,2] Furthermore, the calculation[1] of the branching ratios for the slow π^- reactions in deuterium using the weak coupling $PS(PV)$ theory and treating the nuclear interaction phenomenologically, gives results in reasonable agreement with experiment. We have investigated the K-capture of π^- mesons by He^3 in the $PS(PV)$ theory using Tamor's method. Comparison with reactions in deuterium and hydrogen should provide a test of the weak coupling approximation. There are six competing processes which fall in three categories: the pure absorption, the γ-absorption and the π^0 absorption. Special attention is given to the γ and π^0 absorptions leading to H^3 because of the similarity with the π^- reactions in hydrogen; using the branching ratio given by the hydrogen experiment, it is possible to eliminate the π^0 coupling constants from the expression for their ratio. We estimate that 80 percent of the absorption events are pure absorption, with formation of deuterium in $\frac{1}{3}$ of the cases. The remaining events are shared almost equally (1.2:1) between γ and π^0 absorption. Numerical results including the shape of the γ-spectrum will be given.

* Work supported by the AEC and The French Direction des Mines.
[1] S. Tamor, Phys. Rev. **82**, 38 (1951).
[2] Clark, Roberts, and Wilson, Phys. Rev. **83**, 649 (1951); Durbin, Loar, and Steinberger, Phys. Rev. **83**, 646 (1951).

M12. Absorption of Negative π-Mesons in Helium Gas.* C. P. Leavitt,† *M.I.T.*—Negative π-mesons produced in a beryllium target by the x-ray beam of the M.I.T. synchrotron entered a high pressure cloud chamber[1] filled with helium gas at 200 atmospheres pressure. Every negative meson that stopped in the gas was observed to give rise to a one-pronged star. By means of their curvature in the magnetic field and their range in the gas, some of the prong particles could be positively identified and their energy measured. Most of the particles so far identified have proved to be protons, although in at least one case the particle is heavier than a proton. Photographs of typical events will be shown and their analysis discussed.

* This work has been supported in part by the joint program of the ONR and AEC.
† AEC Predoctoral Fellow.
[1] G. E. Valley and J. A. Vitale, Rev. Sci. Instr. **20**, 411 (1949).

M13. Nuclear Cross Sections for Negative Pions of Energy 109 and 133 Mev.* R. L. MARTIN,† H. L. ANDERSON, AND G. YODH, *University of Chicago*.—Measurements of nuclear cross sections for negative pions at 85 Mev have recently been made by Chedester, Isaacs, Sachs, and Steinberger.[1] They studied the attenuation of a 100-Mev pion beam in various absorbing materials using counters in a geometry poor enough to avoid the effects of Coulomb scattering. We have made similar measurements at 109 and 133 Mev with the result that the observed total cross sections have the geometric values, $\pi A^{\frac{2}{3}}(\hbar/\mu c)^2$, within the uncertainties (15 percent) of this technique. With the possible exception of carbon there is no evident energy dependence in the range 85 to 133 Mev.

* Research sponsored by the ONR and AEC.
† AEC Predoctoral Fellow.
[1] Chedester, Isaacs, Sachs, and Steinberger, Phys. Rev. **82**, 958 (1951).

M14. Meson Fission of Mercury. NATHAN SUGARMAN, *University of Chicago*.—Radiochemical studies are in progress on the fission of mercury by 122-Mev π^- mesons from the University of Chicago synchrocyclotron. Activity and yield measurements have been made on the following fission products: 2.4-hr Br^{83}, 36-hr Br^{82}, 9.7-hr Sr^{91}, 2.7-hr Sr^{92}, 3.7-hr Y^{92}, and 4.5-hr Ru^{105}. There was no activity in the mixed rubidium-caesium fraction or in the barium fraction, thus indicating the absence in reasonable yield of 5.5-hr Cs^{127}, 33-min Cs^{138}, and 85-min Ba^{139}. Comparison of the distribution of the fission products of meson fission of mercury with those of high energy neutron (from 450-Mev protons) fission of mercury indicates that the fission products from the meson reaction are less neutron deficient.

FRIDAY MORNING AT 10:00

Havemeyer 309

(G. C. BALDWIN presiding)

Neutrons

N1. Reflection and Refraction of Neutrons from a Beryllium Mirror.* J. A. HARVEY, M. D. GOLDBERG, AND D. J. HUGHES, *Brookhaven National Laboratory*.—Because of spin-dependent scattering the coherent scattering cross section of a nucleus of a monoisotopic element may be less than the bound atom cross section. This spin dependent scattering arises from the difference in the scattering amplitudes of the two possible spin states of the compound nucleus. The difference in the scattering amplitudes arises from the presence of a nearby resonance. The coherent scattering cross section may be determined from a measurement of the critical angle for total reflection of a collimated beam of neutrons. We have measured the coherent cross section of beryllium by both reflection and refraction of neutrons from a beryllium mirror. Using graphite filtered neutrons which have a cut-off wavelength of 6.69A, we find a critical angle of 39.7′. Assuming no spin-dependent scattering and using the best value of 7.42 barns for the bound atom cross section of beryllium, the critical angle would be 40.0′. Therefore, the spin dependent scattering must be small, and a direct measurement is necessary to obtain a quantitative result.[1]

* Research carried out under contract with AEC.
[1] H. Palevsky and R. Smith, following abstract.

N2. Low Energy Cross Section Measurements of Be with the Brookhaven Slow Neutron Chopper.* HARRY PALEVSKY, *Brookhaven National Laboratory*, AND R. R. SMITH, *Columbia University*.—The spin-dependent scattering in Be can be determined from the total cross-section measurements for wavelengths greater than the Bragg cutoff (3.95A). By cooling the sample to liquid air temperatures, the inelastic scattering is reduced to a minimum. The residual cross section minus the capture then gives an upper limit for the spin interaction. Inelastic scattering theory indicates that as the neutron wavelength increases the inelastic cross section approaches a $1/v$ dependence. In this region an extrapolation to zero wavelength will yield the spin dependent cross section. With the slow chopper we have determined the cross section variation with wavelengths, for various temperatures of the sample. The results give a spin-dependent scattering of <0.03 barn. The inelastic scattering cross section from 5A to 18A can be represented accurately, contrary to theory, by the relation $\sigma=a+b\lambda$ where a and b are temperature dependent parameters.

* Research carried out under contract with the AEC.

N3. Total Cross Sections for 400-Mev Neutrons.* V. A. NEDZEL AND JOHN MARSHALL, *University of Chicago*.—The total nuclear cross sections of several elements for neutrons from the Chicago synchrocyclotron were determined in good geometry using a Čerenkov radiation detector. In the arrangement used, the collimated beam from a beryllium target was passed, through absorbers made of the materials studied, onto a hydrogenous radiator. Observations were then made of the recoil protons at an angle of 9° to the neutron beam. Range measurements of the protons actuating the Čerenkov counter indicated that the neutrons studied in this experiment had an energy spectrum centered at about 406 Mev, with a full width, at half-intensity, of 32 Mev. Preliminary results obtained from the cross-section measurements are as follows: carbon, 0.288 ± 0.004; copper, 1.14 ± 0.02; cadmium, 1.70 ± 0.04; lead, 2.69 ± 0.05, the values in barns and the indicated uncertainties the statistical probable errors of the data obtained.

* This work was supported by the joint program of the ONR and AEC.

N4. Slow Neutron Capture Gamma-Rays.* W. A. THORNTON, JR.,† E. DER MATEOSIAN, H. T. MOTZ, AND M. GOLDHABER, *Brookhaven National Laboratory*.—To study low energy γ-rays accompanying the capture of slow neutrons, we have used either a scintillation counter or a lens spectrometer. The 478-kev line emitted in 95 percent of the disintegrations of B^{10} by slow neutrons is used for energy and intensity calibrations. Discrete γ-ray lines were observed for a number of elements. Of particular interest is a 555 ± 5-kev line found to be emitted from $Cd^{113}+n$ with an intensity of 0.9 to 1.0 per neutron captured. This line coincides in energy with a line known from the K-capture decay of In^{114} to Cd^{114} and may therefore indicate that practically each neutron capture leads to the first excited state of Cd^{114}.

* Research carried out under contract with the AEC.
† Graduate student, Yale University.

N5. Measurements of γ-Ray Energies with a Pair Spectrometer. G. A. Bartholomew and B. B. Kinsey, *Chalk River*.—The coincidence peak obtained with a pair spectrometer exhibits a sharp linear edge followed by a tail toward high magnetic fields. The end point of the peak or the maximum field at which coincidences are obtained corresponds to the production of pairs at the center of the radiator with the electron and positron having equal energy and following orbits in the median plane which graze the inner edges of the slits. An accurate evaluation of the γ-ray energy depends on a measurement of the distance between the inner edges of the slits and the maximum magnetic field. The end point is, in practice, always obscured by a background caused by scattered electrons, and its position must be obtained by extrapolating the linear slope of the peak to zero counting rate and adding a small correction. The magnitude of the correction and its dependence on the geometry of the spectrometer and the γ-ray energy has been investigated theoretically and experimentally. Neutron binding energies obtained by measuring ground-state neutron-capture γ-rays using this method agree well with those obtained by measuring the Q's of (dp) reactions.

N6. Neutron Capture Cross Sections from (n, γ) Reactions.* E. B. Meservey, W. W. Havens, and L. J. Rainwater, *Columbia University*.—Measurements of neutron capture cross sections have been made by detection of capture-gammas emitted from a sample placed in the slow-neutron beam of a neutron velocity selector. Counting rates in scintillation counters near the sample have been plotted against neutron time-of-flight to give a measure of relative (n, γ) cross sections as a function of neutron energy. Orientation studies on indium and silver showed the well-known resonances in these substances; the silver measurements were carried into the thermal region and showed the characteristic $1/v$ slope. Preliminary measurements have been made in the resonance region on samples of Cd, BaO, and SrF_2. Resonances have been detected in Cd at about 27 ev and 90 ev,[1] in Ba at about 25 ev and 101 ev, and in Sr at 3.5 ev. Comparative studies on Cd and Ag in the thermal region roughly confirm measurements by Muehlhause[2] of the relative capture-gamma multiplicity of these two substances.

* This work was supported in part by the AEC.
[1] This resonance may be the same as that reported previously at 110 ev, Coster, Groendijk, and DeVries, Physica 14, 1.
[2] C. O. Muehlhause, Phys. Rev. 79, 277 (1950).

N7. Slow Neutron Resonances in Cs and Pd. H. H. Landon, *Rensselaer Polytechnic Institute*, and V. L. Sailor, *Brookhaven National Laboratory*.—The neutron cross sections of Cs and Pd have been measured from 0.6 ev to 40 ev with a crystal spectrometer using a beryllium crystal as the monochromator.[1] A strong resonance was found in Cs at 5.70 ev. The strength of this resonance obtained with a thick sample was $\sigma_0\Gamma^2=161\pm20$ barns $(\text{ev})^2$. The large thermal cross section of Cs may be attributed to this resonance. Pd has a strong resonance at 31 ev and a weaker one at 12.5 ev. The 31-ev resonance is probably the one previously reported by Goldhaber *et al.*[2] and attributed by them to Pd^{108}. Problems related to the analysis of resonance data will be discussed.

[1] L. B. Borst and V. L. Sailor, Bull. Am. Phys. Soc. 26, No. 6, 15 (1951).
[2] Goldhaber, Lowry, and Sunyar, BNL-C-9, 96 (1949).

N8. Fast Neutron Reaction Cross Sections. E. B. Paul and R. L. Clarke, *Chalk River Laboratories*.—Forty elements have been bombarded with the 14-Mev neutrons from the $T(d, n)He^4$ reaction and the activation cross sections measured. About seventy (n, p), (n, α), and $(n, 2n)$ reactions resulting in known radioactive products with half-lives between a few seconds and a few days have been observed. The counting arrangement has been calibrated using samples containing standardized quantities of radioactive materials. The neutron monitor has been calibrated by counting the α-particles from the $T(d, n)He^4$ reaction. A comparison of the measured cross sections with values predicted by evaporation theory[1] has shown that the charged particle reactions observed for mass number A greater than 100, are from 10 to 1000 times more probable than would be expected from the theory and that the observed $(n, 2n)$ cross sections for A greater than 100 are less than the predicted values by up to a factor of 3. Some possible interpretations of these results are discussed.

[1] Blatt and Weisskopf, M.I.T. Technical Report No. 42 (May, 1950).

N9. Angular and Energy Spectrum of Neutrons Produced in Several Elements Bombarded with 110-Mev Protons. I. Experimental. J. A. Hofmann* and K. Strauch, *Harvard University*.—A measurement has been made of the angular and energy distribution of neutrons with energies larger than 52 Mev produced in several targets by the internal 110-Mev proton beam of the Harvard cyclotron. The neutrons were collimated by slits cut at 0°, 5°, 10°, 16°, and 28° into a 28-in. deep lead block. The neutrons were detected in the usual way by a recoil proton counter telescope, the proton energies being obtained from a differential range spectrum. To increase counting rates the experiment was carried out close to the cyclotron. The effect of the large background in this position was reduced by using (1) quadruple coincidences between stilbane scintillation counters to define the recoil protons, and (2) fast coincidence circuits (resolving time 2×10^{-8} sec) to reduce accidentals to a negligible amount. Less than 2 percent of the detected neutrons did not come through the lead channel. The energy distribution of the protons striking the internal target will be discussed.

* Central Scientific Company Fellow.

N10. Angular and Energy Spectrum of Neutrons Produced in Several Elements Bombarded with 110-Mev Protons. II. Results. K. Strauch* and J. A. Hofmann, *Harvard University*.—Considering the energy distribution of neutrons emitted at 0° with respect to the incident protons, the target nuclei fall into two groups: (1) D, Li, and Be each show a pronounced peak at high energies; the width of this peak can be explained by the energy distribution of the primary proton beam as seen by the internal target and the energy resolution of the telescope. (2) C, Al, Cu, and Pb each emit neutrons decreasing in number with higher energies. When comparing the angular dependence of the free neutron-proton scattering at 90 Mev[1] with the angular distribution of high energy neutrons emitted by the various targets, the same two groups appear: (1) the results with Li, Be, and D appear in agreement with free neutron-proton scattering; (2) Al, Cu, Pb, and C give an increasingly less pronounced angular dependence. These results will be discussed with respect to some models for nuclear reactions at this energy.

* Society of Fellows.
[1] Hadley, Kelley, Leith, Segrè, Wiegand, and York, Phys. Rev. 75, 351 (1949).

N11. Angular Distribution of Fast Photoneutrons.* P. T. Demos, J. D. Fox, I. Halpern, and J. Koch,† *M.I.T.*—A study of the emission of fast photoneutrons has been begun using the M.I.T. linear electron accelerator. The energies and angular distributions of these neutrons and the dependence of these quantities on photon energy and target element is being investigated by means of threshold detectors.[1] With the accelerator providing a thick target x-ray spectrum of maximum energy 16 Mev, the neutrons from lead were observed with high angular resolution in all 4 quadrants. The $P^{31}(n, p)$ reaction was used as the detector. If it is assumed that the angular distribution of these neutrons with respect to the beam has the form $a+b\sin^2\theta$, then $b/a=0.34\pm0.07$. The effects of neutron scattering, neutron background, and photon absorption in the target were kept negligible. Preliminary runs on other heavy elements give anisotropies of the same order of magnitude but the yield for middle weight elements has so far been too low to permit angular distribution measurements.

* This work was supported in part by the joint program of the ONR and AEC.

† On leave from the Institute of Theoretical Physics, Copenhagen, Denmark.

[1] H. L. Poss, Phys. Rev. 79, 539 (1950).

N12. The Neutron Source Strength of Granitic Rock. J. PINE AND P. MORRISON, *Cornell University*.—The light isotope He^3 of gas-well helium is expected to come from this set of nuclear reactions in rock:[1] U, Th→α; Si, Al, etc. (α, n); $Li^6(n, \alpha)H^3$; $H^3(\beta^-)He^3$. We have empirically confirmed the most uncertain of these steps by a direct measurement of the rate of neutron production in igneous rock. The sample was placed in a large neutron counter[2] of measured over-all neutron efficiency about 3 percent, located at a depth underground which eliminated cosmic-ray background. The observed counts gave a number-bias curve appropriate for the B^{10} disintegrations in the BF_3 proportional counters used; gamma-ray pile-up and photoneutrons from the deuterium contained in the paraffin moderator were excluded by direct control experiments; the remaining background had the properties expected from alpha-particle residual contamination of the counters. An alkali granite from the carboniferous of Quincy, Massachusetts, gave a counting rate corresponding to a source strength of 0.5 ± 0.35 neutron per second per ton of rock. To improve the counting rate, an enriched simulated granite was prepared by mixing sand with compounds of the other principal constituents of the rock. Radioactive minerals were finely ground and spread dilutely through the material. When radioactive equilibrium was again reached, the neutron count was made. The results were: 0.028 neutron/second/gram of Th; and 0.066 neutron/second/gram U. Connecting for the effects of alpha-particle self-absorption and neutron absorption, and using the average radioactive content of granitic rock, we find ~0.8 neutron/second/T rock. Such a value is in good agreement with the number calculated for the (α, n) reaction yield, and will give the observed ratio of He^3/He^4.

[1] P. Morrison and D. B. Beard, Phys. Rev. 75, 1332 (1949).

[2] Kindly lent to us by Professor G. Cocconi and Dr. V. Cocconi Tongiorgi.

Invited Paper

N13. Measurement of the Neutron-Electron Interaction by Mirror Reflection. D. J. HUGHES, *Brookhaven National Laboratory*. (30 min.)

FRIDAY MORNING AT 10:00

Schermerhorn 501

(B. P. DAILEY presiding)

Invited Paper

O1. Significance of Microwave Spectroscopy for the Theory of Magnetism. J. H. VAN VLECK, *Harvard University*. (30 min.)

Microwave Spectroscopy

O2. On Rotational Magnetic Moments. RUTH F. SCHWARZ, *Radcliffe College*.—The following expression has been derived for the rotational magnetic moment m_z of the general polyatomic molecule in the $^1\Sigma$ state,[1]

$$m_z=\tfrac{1}{2}\Sigma_\rho\Sigma_{\rho'}[G_{\rho\rho'}P_{\rho'}\cos(z,\rho)+G^*_{\rho\rho'}\cos(z,\rho)P_{\rho'}].$$

Here, z is an axis fixed in space, P_ρ is the rotational angular momentum along a principal axis ρ of the molecule, and $G_{\rho\rho'}$ is a component of a tensor, independent of the rotational state. Since for $\rho'>\rho$, the expectation value of $P_{\rho'}\cos(z,\rho)$ can be shown to be zero for any asymmetrical top, Zeeman measurements on three rotational lines give sufficient data to compute the diagonal elements of the G tensor. Jen has made Zeeman measurements on one H_2O line and two HDO lines.[2] We have derived a theoretical expression for the relation between the magnetic moments of these isotopic molecules and hence have been able to compute the G tensor for H_2O from Jen's data.

[1] J. R. Eshbach and M. W. P. Strandberg, Research Laboratory of Electronics Technical Report No. 184, M.I.T., January 9, 1951.

[2] C. K. Jen, Phys. Rev. 81, 197 (1951).

O3. Some Molecular Constants of Li^6F^{19}.* J. C. SWARTZ AND J. W. TRISCHKA, *Syracuse University*.—Radiofrequency spectra of Li^6F^{19} were observed by the electric resonance method. A mass spectrometer was used to separate the ions of the lithium isotopes given off by the hot wire detector. Data were taken on the $(J, m_J)-(J, m_J')$ transitions: (1, 0) −(1, 1) and (2, 1)−(2, 2) at both strong and weak electric fields. The spectra were characteristic of a molecule with a single interaction of the form $cI\cdot J$ associated with the nucleus of spin 1/2 (fluorine). I is the nuclear spin, J the rotational quantum number and c the interaction constant. The constant c/h was measured as 37 ± 1 kc/sec, a value approximately twice that determined from the magnetic resonance data of Nierenberg and Ramsey.[1] Since line widths for a single transition were 12 kc/sec, no fine structure produced by the Li^6 quadrupole[2,3] and $I\cdot J$ interactions[2] was observed. The product μ^2A, where μ is the electric dipole moment of the molecule and A its moment of inertia, was determined to be $747\pm1\times10^{-76}$ cgs units for the vibrational state $v=0$. μ^2A for the next vibrational state is 4.2 ± 0.1 percent higher than that given above.

* Supported in part by the ONR.
[1] Nierenberg and Ramsey, Phys. Rev. 72, 1075 (1947).
[2] P. Kusch, Phys. Rev. 75, 887 (1949).
[3] Schuster and Pake, Phys. Rev. 81, 157 (1951).

O4. Magnetic Hyperfine Structure in the O_2 Molecule.* S. L. Miller,† M. Kotani,‡ and C. H. Townes, *Columbia University*.—Magnetic hyperfine structure has been observed in the microwave spectrum of $O^{16}O^{17}$ in the 5 mm region. The components of the fine structure transitions which fall between 59,250 and 60,300 mc have been identified and are in agreement with the theory of Frosch[1] which predicts a perturbation Hamiltonian $bI\cdot S+cI_zS_z$ for the $^3\Sigma$ state. Both b and c contain terms belonging to the dipole-dipole and the relativistic interactions between the magnetic moments of the O^{17} nucleus and the unpaired electron spins. Values of $b=-101$ mc and $c=140$ mc fit the observed spectrum well, incidentally corroborating the reported value of 5/2 for the O^{17} spin. These values determine the sign and magnitude of the dipole-dipole interaction and show that the unpaired electrons are primarily in $2p\pi$ orbits. The value of $\psi^2(O)$ obtained further shows that they have approximately 1 percent $2s$ character. The data are consistent with unpaired electron wave functions that are about 90 percent $2p\pi$ and 10 percent $2p\sigma$ in character, where the $2p\sigma$ orbit is 10 percent $2s$ hybridized. We wish to thank Professor A. O. Nier for providing a sample of O^{17} enriched to about 1 percent.

* Work supported jointly by the AEC and the Army Signal Corps.
† AEC Predoctoral Fellow.
‡ On leave from Tokyo University.
[1] R. A. Frosch dissertation, December, 1951, Columbia University.

O5. High Temperature Microwave Spectroscopy-Spectrum of KCl, TlCl.* M. L. Stitch, A. Honig, and C. H. Townes, *Columbia University*.—A microwave stark spectrometer has been successfully developed to operate at high temperatures.[1] Gaseous KCl was examined at approximately 715°C. The $J=2\rightarrow3$ rotational transition was observed for the K^{39} Cl^{35} isotopic species in the $v=0$, 1, 3, and 4 vibrational states. The hyperfine structure of the line was too small to be resolved. Frequencies were determined by wave-meter measurements to facilitate rapid searching, but limited accuracy to ±10 mc.

Transition	frequencies seen	expected
$v=0$	23066 ± 10 mc	23067.3 ± 0.2 mc
1	22918 ± 10 mc	22925.1 ± 0.2 mc
3	22646 ± 10 mc	22640.7 ± 0.2 mc
4	22504 ± 10 mc	22498.5 ± 0.2 mc

The expected values are based on $B_e=3856.4$ mc and $\alpha_e=23.7$ mc obtained by molecular beams techniques.[2] An examination of TlCl at approximately 305°C revealed a rich spectra which cannot be the result of diatomic TlCl. This would indicate the presence in the gas of more complex chlorides of thallium.

* Work supported jointly by the Signal Corps and ONR.
[1] Stitch and Townes, Quarterly Report—Columbia Radiation Laboratory, December 31, 1951, and subsequent CRL reports.
[2] Private communication from Lee, Fabricand, and Carlson.

O6. Observation of Rotational Spectra by Molecular Beam Techniques.* C. A. Lee, R. O. Carlson,† B. P. Fabricand, I. I. Rabi, *Columbia University*.—The molecular beam electrical resonance method has been modified to make possible observation of rotational transitions $J=0\rightarrow J=1$. Because the $J=0$ molecules have a greater polarizability than those of $J>0$, they describe a sigmoid path of greater amplitude than all other molecules in the inhomogeneous fields of the two cylindrical condensers. A suitably disposed stopwire permits passage of a portion of the $J=0$ molecules but excludes almost all the rest. The exciting radiation is introduced through a waveguide into a condenser, permitting observation of the lines in zero field or in a uniform electric field. Because extreme resolution was necessary, one of the chief experimental difficulties lay in achieving sufficient frequency and amplitude stability over long periods of time. To this end automatic frequency regulation of the klystron was employed, using a harmonic of a secondary frequency standard as a reference. The stability achieved made feasible the measurement of spectral lines in KCl, whose width at half maximum was $\sim$18 kc, with an accuracy of >1 part in 3×10^6.

* Supported in part by the ONR.
† AEC Predoctoral Fellow.

O7. The Rotational Spectrum of KCl.* B. P. Fabricand, R. O. Carlson,† C. A. Lee, and I. I. Rabi, *Columbia University*.—The molecular beam electrical resonance method has been applied to investigate the structure of the line resulting from the transition $J=0\rightarrow J=1$ in the molecules $K^{39}Cl^{35}$ and $K^{39}Cl^{37}$. This structure resulting from the nuclear quadrupole interactions in the state $J=1$, for different vibrational states, v, was well resolved. The results are

	$K^{39}Cl^{35}$	$K^{39}Cl^{37}$
B_e mc/sec	3856.352 ± 0.002	3746.565 ± 0.002
α_e mc/sec	23.680 ± 0.001	22.675 ± 0.003
γ_e mc/sec	0.050 ± 0.001	0.047 ± 0.001
r_e cm	2.6665×10^{-8}	

The variations of $(eqQ)_K$, $(eqQ)_{Cl}$, and μ in $K^{39}Cl^{35}$ with vibrational state are shown below.

	$v=0$	1	2	3
$(eqQ)_K$ mc/sec	-5.656	-5.622	-5.571	-5.511
$(eqQ)_{Cl}$ mc/sec	>0.070	-0.080	-0.240	-0.380
μ Debye	10.61		10.82	

The $(eqQ)_{Cl^{37}}$ for $v=0$ is -5.660 mc/sec. The mass ratio of the chlorine isotopes agrees with previous measurements. Attention is drawn to the extraordinary variation of $(eqQ)_{Cl^{35}}$.

* Supported in part by the ONR.
† AEC Predoctoral Fellow.

O8. Lambda-Doubling in a Microwave Spectrum of Nitric Oxide. R. Beringer and E. B. Rawson.—The lambda-doubling in nitric oxide has been observed in the Zeeman levels of the $^2\pi3/2$, $J=3/2$ state. The doubling is observed in a microwave resonance spectrum arising from electric-dipole transitions between the magnetic sublevels. A similar spectrum at somewhat lower resolution has been reported.[1] Because of the level structure the observed line splitting is of the order twice the lambda-doubling. The average splitting (about 1.7 mc/sec) agrees with calculations based on optical band spectrum data. The microwave splitting varies with M_J roughly as indicated by an unpublished theory of M. Karnaugh. The experiments will be described, and correlation with Karnaugh's theory will be discussed.

[1] R. Beringer and J. G. Castle, Jr., Phys. Rev. 78, 581 (1950).

O9. The Zeeman Effect of the Chlorine Nuclear Quadrupole rf Resonance.* Christopher Dean, *Harvard University*.—The first-order Zeeman perturbation of the electric quadrupole energy levels of a nucleus with spin 3/2 interacting with an arbitrary electric field has been computed for all orientations of the magnetic field, and exact solutions have been obtained for special orientations. These results show that the deviation of the electric field gradient tensor from rotational symmetry can be measured and its principal axes located by the Zeeman effect. A superposition of two patterns corresponding to different orientations of the tensor, each having an asymmetry factor $\eta=[\partial^2V/\partial x^2)-(\partial^2V/\partial y^2)/(\partial^2V/\partial z^2)=0.08$ ±0.02, was found in the Cl^{35} resonance in a crystal of p-dichlorobenzene in the phase stable below 30°C. Taken together, the two sets of principal axes specify a single axis of twofold symmetry, agreeing with the classification of this crystal as monoclinic, and the two orientations are interpreted as belonging to the two different molecules in the unit cell. The deviation from rotational symmetry can be attributed to the partial double-bond character of the C—Cl bond, and on this assumption the orientation of the molecules can be specified completely.

* This work was partially supported by the joint program of the ONR and AEC.

O10. The Spin and Quadrupole Moment of Se^{79}.* W. A. Hardy, G. Silvey, and C. H. Townes, *Columbia University*.—Six lines of the quadrupole hyperfine structure of the radioactive nucleus of Se^{79} in the $J=2\rightarrow3$ transition of $O^{16}C^{12}Se^{79}$ have been measured and determine the spin of Se^{79} as 7/2 with a quadrupole coupling constant (eq$Q$) of 754 ± 3 mc. An estimate of the molecular constant q, gives the Se^{79} quadrupole moment $Q=1.2\times10^{-24}$ cm² with an error probably less than 50 percent. The spectroscopy was done in a recording Stark spectrometer with frequency markers placed directly on the recording trace. One microgram of Se^{79} produced by uranium fission was obtained from the Brookhaven National Laboratory, reduced to elemental Se, and reacted with CO to give OCSe. Nuclear shell structure predicts a $g_{9/2}$ or possibly a $p_{1/2}$ state for the ${}_{34}Se_{45}{}^{79}$ nucleus and the observed spin of 7/2 is a clear exception to the single particle, strong spin-orbit coupling model. Goldhaber and Sunyar[1] have, however, predicted the spin of 7/2 for the ground state of Se^{79} from a study of isomeric decay. A nuclear $(g_{9/2})^3$ configuration is indicated in which two particles fail to pair exactly to give zero angular momentum, but give unit angular momentum, instead. The positive quadrupole moment of Se^{79} is consistent with this type of state.

* Work supported by the AEC.
[1] M. Goldhaber and A. W. Sunyar, Phys. Rev. 83, 906 (1951).

O11. The Microwave Spectrum and Structure of Chlorine Trifluoride.* D. F. Smith, *Carbide and Carbon Chemicals Company*.—The microwave spectrum of ClF_3 is that characteristic of an asymmetric top molecule with a wealth of weak lines which have been observed in the 24 to 31 kilomegacycle region. The lower frequency corresponds to a "band head" of a $K_{-1}=1\rightarrow2$ subgroup. The $J=4$, 5, 6, and 7 of this group, together with the $J=5$ of the $K_{-1}=0\rightarrow1$ subgroup near 21 kilomegacycles have been identified for both $Cl^{35}F_3$ and $Cl^{37}F_3$. These lead to internally consistent values of a-c and κ. Together with the $1_{0,1;-1}\rightarrow2_{1,2;-1}$ transitions these yield preliminary values for the moments of inertia (in atomic mass units angstroms²) of $I_a{}^{35}=36.764$, $I_b{}^{35}=109.60$, $I_c{}^{35}=146.56$ and of $I_a{}^{37}=37.019$, $I_b{}^{37}=109.59$, $I_c{}^{37}=146.81$. Since $I_c\approx I_a+I_b$ as well as $I_b{}^{35}\approx I_b{}^{37}$, the molecule is planar, with a C_{2v} axis that is further confirmed by an observed alternation of intensities. These moments of inertia fit an undistorted "T" model with the Cl at the intersection of the two arms. The two similar ClF bonds (1.70A) are longer than the unique ClF bond (1.56A). The FClF angles are 90° within the precision with which this angle is determined. This structure is in fair agreement with the preliminary x-ray structure that had been found by Dr. Burbank of the K-25 Laboratories. The hyperfine structure can be consistently fit to values of $\chi_{aa}(Cl^{35})$ (along the straight FClF line) $=-81$ mc, $\chi_{bb}(Cl^{35})$ (along the unique ClF bond) $=-65$ mc so that $\chi_{cc}(Cl^{35})=146$ mc.

* This document is based on work performed for the AEC by Carbide and Carbon Chemicals Company, at Oak Ridge, Tennessee.

O12. Anomalies in the Hyperfine Structure of ICN.* A. Javan and C. H. Townes, *Columbia University*.—Hyperfine components of the $J=3\rightarrow4$ transition of ICN in the excited vibrational state $v_2=1$ apparently show varying amounts of l-type doubling. The variation is proportional to the separation of the particular hyperfine component from the theoretical position of the transition without hyperfine structure, and is as large as 6 mc. This anomaly can be attributed to the fact that the electric field gradients are not symmetric about the axis of the molecule when the molecule is bent because of vibration. The value of the asymmetry parameter

$$\eta=\left(\frac{\partial^2v}{\partial x^2}-\frac{\partial^2v}{\partial y^2}\right)\Big/\frac{\partial^2v}{\partial z^2}$$

is 0.0045. This is about five times larger than the value to be expected from a bending of the molecular bonds with no change in their structure. Its size must in part be the result of an asymmetry of the I—C bond about its axis produced by the bending of the molecule. Other anomalies in the ICN excited states are being studied.

* Work supported jointly by the Signal Corps and ONR.

O13. Anisotropy in Paramagnetic Resonance in Free Radicals.* C. Kikuchi and V. W. Cohen, *Brookhaven National Laboratory*, and John Turkevich, *Princeton University*.—We have observed the paramagnetic resonance absorption in Picryl-n-Amino Carbazyl by mounting the specimen at the center of a k band cylindrical cavity. The sample was mounted at the end of an axial quartz rod and could thus be rotated about an axis perpendicular to the applied magnetic field. With samples which appear to be single crystals, the line half width is about 0.5 gauss. For a certain orientation of the crystal with respect to the axis, the position of the line is independent of rotation. For other orientations, the line shifts with respect to rotation by as much as 7 gauss toward the direction of high applied field. The periodicity of this shift is 180°. The g values corresponding to the extremes of the range are 2.0024 and 2.0041 using the value of 2.0036[1] for $\alpha-\alpha$ diphenyl-β-picryl hydrazyl. A similar effect was observed for the hydrazyl but the basic line width was about one gauss with the extremes resulting from rotation of about 5 gauss. These directional effects might be attributed to diamagnetic effect of the molecule.

* Research carried out under contract with the AEC.
[1] C. H. Thomas and J. Turkevich, Phys. Rev. 77, 148 (1950).

Friday Morning at 9:45

Pupin 428

(Gregory Breit presiding)

Scattering Theory; Nuclear Shell Theory

P1. Nuclear Shell Interactions. Katharine Way and Marion Wood, *National Bureau of Standards*.—Neutron and proton binding energies in the region from Tl to Cm have been computed from experimental Q values, α-systematics,[1] and β-decay energies. Interpreted on shell ideas, the results show: (1) For $Z=82$, the shell interaction of the new neutron shell (starting with 127) is that predicted by the calculation of M. G. Mayer.[2] (2) When both neutrons and protons are put into new shells (protons above 82, neutrons above 126) one finds a strong, quickly saturated, spin dependent $n-p$ interaction with magnitude ≤ 0.8 Mev per pair. This interaction causes neutron binding energies, B_n, to decrease as N_n/N_p increases so that, for Z constant, a plot of $B_n(A)$ near a shell edge is quite different from that found for electrons near an atomic shell edge. Proton binding energies show an added electrostatic repulsion effect. In the course of the study, a new β-systematics was developed which exhibits clearly the shells at $Z=82$ and $N=126$ but no further shells for higher values of Z and N.

[1] Seaborg, Perlman, and Ghiorso, Phys. Rev. **72**, 26 (1950).
[2] M. G. Mayer, Phys. Rev. **78**, 22 (1950).

P2. The Line of Beta-Stability. A. E. S. GREEN, N. ENGLER, AND N. J. MARUCCI, *University of Cincinnati.*—We present a chart of the nuclides based upon a transformation involving a simple empirical expression for the line of minimum mass. On this chart beta-stable nuclides are located at points which scatter around the horizontal axis. Our chart is designed to magnify greatly certain trends and irregularities in the tendencies of nuclides. By using it we show (a) the experimental line of β-stability, (b) the effects associated with pairing and magic numbers, (c) the lines of minimum mass according to the semiempirical mass formula with various sets of constants, (d) the limits of β^--, β^+- and K-capture stability according to experiment and the different semiempirical mass formulas, and (e) the relations between the lines of minimum mass and the corresponding lines of maximum binding energy. We conclude with an evaluation of various semiempirical mass equations from several standpoints which are related to beta-stability.

P3. The Hyperfine Structure Anomaly and Models of Nuclear Structure. B. T. FELD, *M.I.T.*—The hyperfine structure anomaly is defined as the difference from 1 of the ratio of the magnetic moments of two isotopes, as determined from their hyperfine structure in atomic s-states by application of the Fermi-Segré formula, divided by the ratio of the moments as observed by nuclear induction. As suggested by Bitter and Kopfermann and demonstrated by A. Bohr and Weisskopf, the hfs anomaly arises from a difference, between the nuclei involved in the distributions of nucleon moments and currents which give rise to the nuclear moments. Anomalies have been observed for $Li^{6,7}$, $K^{39,41}$, $K^{39,40}$, $Rb^{85,87}$, and $Tl^{203,205}$ (atomic ground state $^2p_{\frac{1}{2}}$). These results can be compared with theoretical estimates, based on different nuclear models. In general, reasonable agreement is obtained for models which are, in their essential features, based on the independent particle model with spin-orbit coupling. Particular consideration has been given to the application of the theory to odd-odd nuclei. For the case of K^{40}, unfortunately, all the models which have been investigated (and which are capable of yielding the observed spin and nuclear moment) predict essentially the same anomaly.

P4. Emperical Evaluation of Unpaired Spin Effects for Protons and Neutrons.* CHARLES D. CORYELL AND HANS E. SUESS, *Massachusetts Institute of Technology and the U. S. Geological Survey.*—By taking as a reference point even-Z and even-N nuclides, the energy of nuclides may conventionally be expressed $E(Z, N)=f(Z, N)+\pi$ (for an unpaired proton) $+\nu$ (for an unpaired neutron). The term δ was introduced by Bohr and Wheeler for either π or ν, so that their δ_A equals $\pi+\nu$. Experiment[1] shows that in some regions π exceeds ν, i.e., for heavy odd-A nuclides, and just above the neutron closed-shells $N=50$ and $N=82$. The $\pi-\nu$ differences in Mev are recorded[1] as 0.2 (Glueckauf), 0.6, and 0.7 (Suess) for the three regions respectively. Consideration of the statistics of Z values of odd-A nuclides shows that $\pi\leq\nu$ in other regions where odd-Z nuclides are favored. For the regions above $Z=14$, $Z=28$, and $Z=50$, ν exceeds π by about 0.5 Mev. As with N-shells other than 126, the $\pi-\nu$ difference fades away with increasing A. These $\pi-\nu$ effects added to considerations[2] of parabolic depth B_A and of stablest charge Z_A, for given A, explain almost quantitatively the instability of A^{37}, the surprisingly low decay energies of Zr isotopes, and the β-energetics of isotopes of Tc, Pm, At, and Fr.

* Supported in part by the AEC.
[1] E. Glueckauf, Proc. Phys. Soc. (London) **61**, 21–33 (1948); L. Kowarski, Phys. Rev. **78**, 477 (1950); H. Suess, Phys. Rev. **81**, 1071 (1951).
[2] Coryell, Brightsen, and Pappas, Bull. Am. Phys. Soc. **26**, No. 6, 36, October, 1950.

P5. First Forbidden Beta-Transitions.* T. AHRENS† AND E. FEENBERG, *Washington University.*—The general theory of first forbidden beta-transitions involves seven nuclear matrix elements in the nonrelativistic approximation. The number of independent parameters can be reduced to four with the help of the relation, $(W_f-W_i)(f|X|i)=(f|[H, X]|i)$. Here W is an energy eigenvalue, X a coordinate type first forbidden operator, H the nuclear Hamiltonian [a sum of H_0 (free particles), H_c (Coulomb interaction), and H_v (specifically nuclear interactions)]. $[H_0, X]$ and $[H_c, X]$ are easily evaluated, but $[H_v, X]$ presents difficulties because H_v for complex nuclei is essentially unknown. However knowledge of the explicit form of H_v is not required; the matrix elements of $[H_v, X]$ can be estimated by physical arguments based on the semiempirical nuclear energy surface and the general validity of shell model considerations.

* Supported in part by the joint program of the ONR and AEC.
† AEC Predoctoral Fellow.

P6. Magnetic Moments of Even-Odd Nuclei. JACK P. DAVIDSON,* *Washington University.*—As the ground states of odd-A nuclei are generally considered to be predominantly of the doublet type, one may write for the pure doublet approximation, $\Psi_I=\alpha\Psi_{L=I-\frac{1}{2}}+(1-\alpha^2)^{\frac{1}{2}}\Psi_{L=I+\frac{1}{2}}$, a linear combination of pure $L-S$ coupling states. The deviations of the nuclear magnetic moments from the Schmidt limits are interpreted as the failure of $L-S$ coupling and a simple interpolation procedure which preserves the parity quantum number is applied to compute the statistical weight of the components with $L=I+\frac{1}{2}$ and $L=I-\frac{1}{2}$. The results below odd-N or -$Z=53$ are sufficiently regular to be used to compute the magnetic moment of several odd neutron nuclei.

* Washington University Fellow.

P7. Connection Between Scattering and Derivative Matrices. E. P. WIGNER, *Princeton University.*—In problems of simple scattering, both the scattering function S and the derivative function R are analytic. The latter is the ratio of the wave function to its derivative at a fixed point outside the range of the potential; it is a real function of the energy $R(k)=R(-k)=R(k^*)^*$. The connection between the two functions is $S=(1+ikR)(1-ikR)^{-1}\exp(-2ika)$ and S satisfies the relations $S(-k)=S(k^*)^*=S(k)^{-1}$. The poles of S, considered as function of the complex variable k, lie either in the lower half plane or on the imaginary axis; those of R, considered as function of the energy or of k^2, lie on the real axis and their residues are negative. Schutzer and Tiomno have shown that the above properties of S follow from those of R. Although the number of arbitrary constants in both R and S is the same, namely, equal to the number of poles, it can be shown that the constants in the latter have to satisfy certain inequalities if the S is to be derivable from a permissible R. The simplest of these states that the center-of-mass of the poles of S lies in the lower half-plane if their number is even.

P8. Neutron-Proton Scattering with Spin-Orbit Coupling; Formal Theory. JOHN M. BLATT, *University of Illinois* AND L. C. BIEDENHARN, *Oak Ridge National Laboratory.*—Neutron-proton scattering in the triplet spin state is discussed under the following assumptions about the nuclear forces. (1) They are conservative, (2) they allow time-reversal (i.e., the reciprocity law is valid), (3) the spin vectors of the neutron and proton enter in a symmetrical way, so that the total spin of the system is preserved during the collision, and (4) the forces have a finite range. We do *not* assume that the forces can be derived from a potential function. The scattering matrix for the system is expressed in terms of the minimum number of real, independent parameters. These parameters are related to the asymptotic behavior of the solutions of the wave equation for large distances. A general expression is given for the differential scattering cross section in terms of these parameters. The energy dependence of these parameters near zero energy can be predicted uniquely on the basis of assumptions (1) to (4) above. While many of these results are well-known, the derivation given here shows that they hold under much more general assumptions than the usual proofs would indicate.

P9. Nucleon Scattering with Repulsive Core Potentials. M. A. PRESTON, J. R. BIRD, AND J. SHAPIRO, *University of Toronto.*—Interactions of the type proposed by Jastrow[1] but with finite repulsive potentials are considered. Thus for a given "shape" of potential, there are four parameters in the singlet interaction, two ranges and two potential strengths. The scattering data at energies where relativistic effects are assuredly not important are studied to see to what extent these parameters are fixed. The results obtained will be discussed.

[1] R. Jastrow, Phys. Rev. 81, 165 (1951).

P10. Application of the Variational Method to Scattering by a Square Well Potential.* J. MAYO GREENBERG, *University of Maryland.*—The scattering by a square well potential is calculated by the variational method[1] by using as initial trial functions a plane wave with the appropriate wave number, and an approximate internal wave function obtained[2] by summing the spherical Bessel function expansion of the wave function with the assumption that the well is large compared with the incident wavelength. In order to obtain an expression in closed form for the variational result, one must resort to exactly the same approximation as is used by Hart and Montroll. Use of the approximate internal wave function then leads to the same scattering function. In fact, this result is also obtained by using the approximate internal wave function in the correct integral equation.[3] Comparison of the two results will be made with several exact and experimental values.

* Work supported by the ONR.
[1] W. Kohn, Phys. Rev. 74, 1763 (1948).
[2] R. W. Hart and E. W. Montroll, J. Appl. Phys. 22, 376 (1951).
[3] E. W. Montroll and R. W. Hart, J. Appl. Phys. 22, 1278 (1951).

P11. The Effect of a Singular Triplet Tensor Interaction on $P-P$ Scattering Below 10 Mev. EDWIN A. CROSBIE, *University of Pittsburgh.*—Christian and Noyes[1] have shown that the 32- and 340-Mev $P-P$ scattering data are consistent with the scattering to be expected from the usual singlet square well interaction of the form ∓ 18 Mev exp $(-r/R)\times(r/R)^{-2}$, $R=1.6\times10^{-13}$ cm. Numerical solution of the differential equations using this interaction gives the following P-wave tensor phase shifts at the indicated energies: $E=8$ Mev, $\delta_{12}=-0.38°$, $\delta_{11}=2.50°$, $\delta_{10}=-3.13°$; $E=6.85$ Mev, δ_{12}: $-0.32°$, $\delta_{11}=2.04°$, $\delta_{10}=-2.61°$. The effect of the P-wave scattering on the apparent S-wave phase shift at these energies is investigated. It is found that an accuracy of about 1 percent in energy plus cross section measurements would be sufficient to detect the singular tensor interaction at energies around 8 Mev. Comparison at 6.85 Mev with the Rouvina[2] nonliquid nitrogen data shows that the calculated apparent S-wave phase shifts as a result of this interaction, as a function of angle is just within the accuracy but does not provide the best fit for the experimental points.

[1] Christian and Noyes, Phys. Rev. 79, 85 (1950).
[2] Rouvina, Phys. Rev. 81, 593 (1951).

P12. A Variational Principle for k cotδ. S. I. RUBINOW AND HERMAN FESHBACH, *M.I.T.*—In the analysis of (n, p) and (p, p) scattering, the quantity $k\cot\delta$, where k is the wave number and δ is the phase shift, is of primary importance for calculating the scattering cross section. Both Schwinger and Hulthen have introduced variational principles for $k\cot\delta$; these, however, suffer from the defect that the trial wave functions contain $k\cot\delta$, the quantity that is sought. While Hulthen has reformulated his method so that this defect is absent, the expression he uses to obtain $k\cot\delta$ is no longer stationary with respect to variations in the wave function. A new variational principle for S-state scattering is introduced which utilizes a stationary expression for $k\cot\delta$ in terms of the "inside" wave function. The latter is independent of $k\cot\delta$. Consequently, the scattering length $1/\alpha$ and the effective range r_0 can be calculated directly. The Born approximation may be obtained by assuming an appropriate trial function. The method is illustrated for the exponential well potential with a simple trial function involving only one parameter. The results obtained for α and r_0 are in very good agreement with the exact solution (given by Blatt and Jackson).

FRIDAY MORNING AT 9:00

McMillin

(C. C. LAURITSEN presiding)

Business Meeting of the American Physical Society

(G. P. HARNWELL presiding)

Invited Papers

Q1. Big Molecules in Biological Systems. R. W. G. WYCKOFF, *National Institutes of Health.* (40 min.)

Q2. Some Recent Experiments with High Centrifugal Fields. J. W. BEAMS, *University of Virginia.* (40 min.)

Q3. Shock Waves and Their Interactions. WALKER BLEAKNEY, *Princeton University.* (40 min.)

FRIDAY MORNING AT 9:45

Pupin 301

(S. C. BROWN presiding)

Business Meeting of the Division of Electron Physics

Symposium of the Division of Electron Physics

R1. Ionization and Recombination Processes in the Afterglow. M. A. BIONDI, *Westinghouse Research Laboratories.* (40 min.)

R2. The Magnetic Moment of the Electron. P. KUSCH, *Columbia University.* (35 min.)

R3. Recent Developments in the Physics of Counters. S. A. KORFF, *New York University.* (35 min.)

FRIDAY AFTERNOON AT 2:15

McMillin

Joint Ceremonial Sessions of APS and AAPT

(J. H. VAN VLECK presiding)

Retiring Presidential Address of the American Physical Society

S1. Some Investigations of Light Nuclei. C. C. LAURITSEN, *California Institute of Technology.*

(M. W. ZEMANSKY presiding)

Presentation of the Oersted Medal of the AAPT

Response by the Oersted Medallist

S2. Opportunities and Rewards in Physics Teaching. ANSEL ALPHONSE KNOWLTON, *Reed College (retired).*

Tenth Richtmyer Memorial Lecture of the AAPT

S3. Large-Cyclotron Research at the University of Chicago. ENRICO FERMI, *University of Chicago.*

FRIDAY AFTERNOON AT 3:20

Schermerhorn 501

(G. E. KIMBALL presiding)

Chemical Physics and Biophysics

SA1. Fourier Transforms and Intensities from Crystalline Proteins.* DOROTHY WRINCH, *Smith College.*—Information is accumulating in published vector maps of crystalline native proteins compatible with the existence, in such crystals, of structures of globular type (and indeed cage structures), as suggested by the writer in 1936. An attempt is therefore being made, by way of Fourier transforms, to derive a structural type, in the first instance spherical, whose transform has turning points at distances from the origin ~1/10A, ~1/4.7A, i.e., in the ratio ~1:2.1. Previous studies[1] show that the ratio is 1:1.58 for the solid sphere and increases for shells, up to 1:1.73 for the spherical surface. This suggests the ratio will be further increased with negative interiors for the shells, a feature which is independently suggested by the fact that our concern is with structures reduced to $\bar{\rho}$, the average electron density in the crystal.[2,3] It has now proved possible to reach the required ratio with a thin shell, provided only that the density of the interior is sufficiently negative, i.e., far enough below $\bar{p}$.

* This work is supported by the ONR.
[1] D. Wrinch, *Fourier Transforms and Structure Factors* (1946).
[2] D. Wrinch, Phil. Mag. **27**, 490 (1939).
[3] D. Wrinch, Acta Cryst. **3**, 475 (1950).

SA2. The Effect of Pressure on the Viscosity of Higher Hydrocarbons and Their Mixtures. WAYNE WEBB, EDWARD M. GRIEST, AND ROBERT W. SCHIESSLER.—Using the rolling-ball method, the viscosity of seven pure hydrocarbons (C_{25}–C_{26}) and three binary mixtures has been measured between 15 and 50,000 psi at 100°, 140°, 210°, and 275°F. The hydrocarbons included isoparaffinic, cycloparaffinic, aromatic, and cycloparaffinic-aromatic compounds. The increase in viscosity with pressure was found to be strongly dependent on molecular structure, a 20-fold disparity in relative viscosity existing among the extremes in structure for the same pressure interval. The viscosity-temperature coefficient, $1/u\ (du/dT)$, increases with increasing pressure. Each of the binary mixtures studied, which corresponded in molecular weight and average molecular structure to a single pure compound, was found to exhibit the same behavior as the analogous pure liquid to within 5 percent in spite of a 50–100-fold increase in viscosity with pressure. This remarkable agreement was interpreted as meaning that the viscosity of these high molecular weight compounds is some additive function of their constituent groups, irrespective of whether these groups are combined in the same or different molecules, as long as the basic molecular symmetry is unchanged.

SA3. The Influence of Specific Volume on the Viscosity-Pressure Behavior of Some Hydrocarbon Liquids. EDWARD M. GRIEST, WAYNE WEBB, AND ROBERT W. SCHIESSLER.—It is suggested that the increase of kinematic viscosity with pressure at constant temperature is related to the attendant decrease in specific volume through the Lennard-Jones potential function in the relatively simple equation, $\log Z=\log Z_0+K/T(-1/v^2+v_0^2/v^4)$, where the subscript indicates the value at atmospheric pressure. The four hydrocarbons for which experimental density data are available are in good accord with this relation. A correlation exists between the quantity (K/T) and the Eyring activation energy for viscous flow as derived from the viscosity-temperature behavior. Although the relationship is not sufficiently precise to permit a reasonably accurate calculation of the viscosity at any given pressure from the atmospheric viscosity-temperature coefficient and the specific volume, it does constitute a more simple and rigorous proof of the interdependence of the effects of pressure and temperature on viscosity than has been described previously.

SA4. Energy Loss of Deuterons in Hydrocarbons. J. W. PREISS AND ERNEST POLLARD, *Yale University*.*—The use of ionizing radiation to measure the size and shape of large organic molecules requires a knowledge of the rate of energy loss of fast charged particles in material composed of carbon, nitrogen, oxygen, and hydrogen. The effective ionization potential of carbon is not well known. To measure this an absorption cell has been constructed which permits the determination of the range of analyzed deuterons in various gases. Preliminary measurements on ethylene and acetylene as compared to air indicate that the effective ionization potential of carbon is 58 5 ev.

* Assisted by the joint program of the ONR and AEC.

SA5. Effect of Deuteron Bombardment on the Serology of Tobacco Mosaic Virus. E. POLLARD AND A. E. DIMOND, *Yale University* and Connecticut Agricultural Experiment Station.*—It has previously been shown that deuteron bombardment removes the infectivity of tobacco mosaic virus if a deuteron passes through an area only slightly smaller than the area of the accepted infectious unit of the virus. Further studies have shown that the same cross section per deuteron for inactivation is found when the temperature of the virus is raised while the bombardment takes place. Thus, as regards infectivity the virus appears to act as a single highly sensitive unit. When the ability of the virus to combine with specific antiserum is measured a completely different result is obtained. It proves possible to subject tobacco mosaic virus to bombardment which reduces the infectivity to below one percent without measurable effect on its ability to combine with antibody. It is thus clear that the action of primary ionization in removing infectivity corresponds to some very slight molecular change, which is far less than is needed to alter the surface configurations required for serological combination. If this should prove to be general for all viruses, it offers promise as a method of temporary immunization.

* Assisted by the AEC.

SA6. Electron Inactivation of Enzymes and Viruses. M. SLATER,* *Yale University*.†—The previously reported[1] study of the inactivation of dry preparations of several enzymes and viruses, using a 2-Mev electron beam, has been completed. The molecules studied (catalase, urease, invertase, chymotrypsin, hemoglobin, T-1 bacteriophage, and tobacco mosaic virus) all gave exponential survival curves. Using conventional target theory, the ionization sensitive volume of the molecules can be determined from these curves and compared with the known sizes of the molecules, thus indicating the fraction (between $\frac{1}{5}$ and 1) of the molecule which is sensitive to radiation. These volumes, determined by low ion-density electrons, can also be compared with cross sections measured by high ion-density deuterons.[2] The agreement between them gives good verification of the ion density predictions of the target theory and is experimental evidence that the energy loss per *primary* ionization is the same (110±10 ev) in both gases and solids.

* Now at Oak Ridge National Laboratory, Oak Ridge, Tennessee.
† Assisted by AEC and ONR.
[1] M. Slater, Phys. Rev. **83**, 231 (1951).
[2] E. C. Pollard, American Scientist **39**, 99 (1951).

SA7. Irradiation of *B. subtilis* with Low Voltage Electrons. MARGUERITE DAVIS,* *Yale University* (introduced by Franklin Hutchinson).—The effect of the differential penetration of slow electrons was studied as a means of investigation of the internal organization of living material. Since the energy of the electron is directly related to its depth of penetration, the variation of survival after irradiation can be correlated with the energy of the bombarding particle and its range. As an application of this, low voltage (100–1600 volts) electrons were used to bombard dry *B. subtilis* bacterial spores in vacuum. No effect was seen up to 200 volts; at this point the survival suddenly dropped to a plateau around 50 percent survival extending to 900 volts. Above 900 volts, the survival dropped rapidly to zero by 1600 volts. Dose survival curves were taken at different voltages and with doses of 10^{15} to 10^{17} electrons/cm^2. The slopes of the curves varied with the voltage and a trail off at high doses was seen up to relatively high voltages where the survival goes to zero at high doses. Using Lea's[1] figures for ranges of low voltage electrons in tissue, the position and size of the sensitive volume within the spore can be calculated.

* Assisted by the AEC.
[1] D. E. Lea, *Action of Radiation in Living Cells* (Macmillan Company, New York, 1947).

SA8. The Bombardment of Biological Molecules with Slow Electrons.* FRANKLIN HUTCHINSON, *Yale University*.—In irradiating biological material with the usual types of ionizing radiations (e.g., x-rays, fast deuterons, etc.) the energy release is the order of 100 ev per primary ionization, which is very large compared to the chemical bonds which hold the material together. Some light might be shed on the mechanism by which biological systems are inactivated by determining this inactivation under irradiation of slow electrons of energies ranging from 0 to 100 volts. This is analogous to the classic Franck-Hertz experiment measuring the excitation potentials of atoms. The target must be only one molecule thick, since very slow electrons cannot penetrate through one molecule to hit another beneath it. Thus it is convenient to irradiate monomolecular layers of protein molecules, using the technique previously described.[1] With monomolecular layers of bovine serum albumin, an inactivation curve has been determined which shows that electrons of less than 16 ev energy are able to inactivate the molecule.

* Assisted by the AEC.
[1] F. Hutchinson, Phys. Rev. 82, 303 (1951).

FRIDAY AFTERNOON AT 3:20

Havemeyer 309

(L. MARTON presiding)

General Physics

SB1. Dynamics of Supernovae. LYLE B. BORST, *University of Utah.*—The light curves of supernovae of type I are characterized by an exponential tail of 55 ± 5 day half-life, experimentally identical to the half-life of non-ionized Be^7 ($T_{\frac{1}{2}}=53d$). This may be quantitatively accounted for by assuming 10^{32} g Be^7 as the energy source in the tenuous expanding gaseous shell observed after explosion. The proposed mechanism for the production of the beryllium involves a nonequilibrium rate controlled endothermic reaction between alpha-particles during the gravitational collapse of the star.

SB2. A New Mutual Inductance Formula. MILAN W. GARRETT, *Swarthmore College.**—For two axially symmetric systems whose axes intersect at angle γ,

$$M=q_0p_0+\sum_{n=1}^{\infty} q_np_n(r_2/r_1)^nP_n(\cos\gamma)/n(n+1).$$

Compute central-field constants q_n[1] from primary coordinates, remote-field constants p_n from the secondary. Unit radii are, respectively, r_1 and $r_2(<r_1)$. For the coaxial case, choose single or multiple origins for best convergence and to suppress alternate terms. The new expression resembles Maxwell's zonal harmonic formula, with loop constants generalized and zero order added. It includes or replaces in working practice most widely used formulas involving circular filaments, disks, thin or thick solenoids (Gray, Lorenz, Searle-Airey, Roiti, Rosa, Snow, Grover, etc.), but covers also new cases. Suppression of algebraic detail permits simpler and more accurate computation; here, all factors are found and checked, to high orders if needed, by simple recurrent relations. Convergence is accurately foretold by inspection. Study of isolated constants q_n, p_n permits new flexibility in system design. A simple extension covers parallel axes.

* Work supported by the ONR and the Research Corporation.
[1] Milan W. Garrett, J. Appl. Phys. 22, 1091 (1951).

SB3. Stress-Induced Noise in Cables.* THOMAS A. PERLS, *National Bureau of Standards.*—Stress-induced cable noise interferes with the transmission of signals in many different types of measurement, control, detection, and communication. The present investigation was undertaken in connection with the design and evaluation of very small barium titanate transducers for acceleration and pressure measurements. A quantitative theory of the mechanism of noise generation predicts a triboelectric separation of charge as a result of intermittent contact between the insulating dielectric and either of a pair of conductors. The necessary redistribution of charge produces a current pulse through the terminating network. Quantitative predictions of this theory are verified by a series of simple experiments. *Stress-induced noise is practically eliminated in cables having conductive coatings both inside and outside of the insulating dielectric.* Comparison of such an experimental, light, flexible, coaxial cable, 0.07 inch o.d., with a standard microphone cable of similar dimensions, shows a reduction in signals caused by twisting and squeezing by a factor of at least 200. There appears to be no limitation on arrangement and number of conductors, or on size and flexibility of cables made by this method. An industrially applicable method of construction will be suggested.

* Work done under a cooperative project on Basic Instrumentation partially sponsored by the ONR, AF, and AEC.

SB4. Noise and Dissipation.* JOHN M. RICHARDSON.†—The connection between noise (producing deviations of observables from their average values) and dissipation (measured by the irreversible part of the drift of these average values toward equilibrium) is investigated in a rigorous and elementary way for any system near equilibrium. In contrast to other work our treatment considers explicitly a large isolated system whose initial nonequilibrium distribution of states is an exponential of a linear combination of the observables. The set of averaged observables, considered as a vector, when operated upon by a suitable impedance matrix, is assumed to vanish except for a correction of short duration. The final result expresses the spectral density matrix of the noise in terms of the Laplace transformed impedance matrix and certain variance matrices of thermodynamic significance. In the classical treatment of voltage fluctuations and resistance, our result agrees completely with the well-known theorem of Nyquist[1] if the impedance is of a restricted type. The connection with the recent work of Callen and Welton[2] will be discussed.

* This research is a part of the work being done at the Bureau of Mines supported by the Air Materiel Command.
† Head, Kinetics Section, Explosives and Physical Sciences Division, Bureau of Mines, Pittsburgh, Pa.
[1] H. Nyquist, Phys. Rev. 32, 110 (1928).
[2] H. B. Callen and T. A. Welton, Phys. Rev. 83, 34 (1951).

SB5. A Constriction Type of Electromechanical Filter Employing a Shear Mode.* SHEPARD BARTNOFF AND CHARLES R. MINGINS, *Tufts College.*—A laminar type of system is considered as the mechanical part of an electromechanical filter with piezoelectric input and output transducers. The different laminae all consist of the same aeolotropic material but have different cross sectional areas. For the transmission of face shear vibrations, it is shown that the system has filter properties analogous to those of a sound filter system consisting of segments of pipe with varying cross sections. Expressions are derived for the band width, the power transmission coefficient of the filter, and for the nature of the variations of these quantities with changes in the physical dimensions of the system elements and also with changes in the number of laminae.

* This work is sponsored by the U. S. Army Signal Corps.

SB6. Grid Bar Mask Focusing in a Color TV Tube. JENNY E. ROSENTHAL.—Most color TV tubes proposed use the shadow properties of a grid bar mask to keep the electron beam from striking any but the desired phosphor color whether applied in lines or dots. Such shadow effects decrease the effective intensity of the electron beam hitting the phosphor to a small fraction of its value at the electron gun. This loss of efficiency is avoided if the shadow property of the grid bar mask is eliminated by suitable design and replaced by a contraction of the area scanned by the beam after it passes through the mask. This is accomplished by the Deserno effect, which is essentially focusing in a transverse electrostatic field generated, in this case, by maintaining a fixed small potential difference between alternating grid bars. As shown previously,[1] a deflection field applied between the grid bars and the conducting coating on the face plate deflects the beam on the different color phosphor strips. Calculations are given on the magnitude of the potentials and the design of the grid bar mask.

[1] Jenny E. Rosenthal, Phys. Rev. 82, 325 (1951).

SB7. A Device for Converting a Shaft Rotation to an Input for a Digital Computer. DONALD H. JACOBS AND SEYMOUR SCHOLNICK, *The Jacobs Instrument Company*.—This device comprises an input shaft, a rotating disk with pulses recorded magnetically on its periphery at equal angular intervals, and a magnetic pick-up head for reading these pulses. The output of the pick-up passes through a gate to a counter. The rotating disk is mounted coaxial with, and adjacent to, the input shaft. Electrical means are used to gate pulses from the pick-up to the counter during the interval that a given point on the disk rotates between a reference point and an arm connected to the input shaft. The number in the counter represents the shaft rotation angle in terms of the radix of the arithmetic system employed by the computer. The devise imposes no torque requirements on the input shaft, and permits any desired degree of angular accuracy. A new reading of input angle is obtained for each rotation of the disk, and the accuracy of measurement is not affected by the disk's rotational speed. Readings of the shaft's angular position can be made as frequently as necessary in any practical case. A 3-in. disk gives an accuracy of $\frac{1}{8}°$ when a magnetic pick-up is used, and appears capable of about 1-minute accuracy when an optical pick-off is employed. The devise is capable of indicating angles with either positive or negative signs relative to a given reference point. It can be used in conjunction with either serial or parallel computers.

SB8. Radio Propagation Beyond the Horizon and the Surface Refractive Index. THOMAS J. CARROLL.* *National Bureau of Standards*.—For the bilinear model of the index of refraction of the normal troposphere, Furry's theory shows that the attenuation of all the modes beyond the horizon is a function of the surface index of refraction, not its gradient, as in the conventional linear model of standard refraction. Pickard and Stetson have demonstrated a strong correlation between changes in average observed fields at 92.8 Mc over a 167-mile path and the surface index, which therefore is readily explained by the bilinear model. Similarly, a model on which the index decreases exponentially from its surface value to unity at great heights will likewise have characteristic values giving attenuation rates depending primarily on the surface index, not its gradient. Since the surface index is easily computed from ordinary meteorological data, renewed hope is raised that simple surface index observations may permit normal seasonal field strength changes to be inferred, at least in the absence of ducts. 1940 observations by Englund, Crawford, and Mumford, and the hypothesis of partial internal reflection of the lobe structure by the troposphere also indicate by an independent argument that surface index of refraction not its gradient, is the important meteorological parameter in normal propagation beyond the horizon.

* Now at Massachusetts Institute of Technology.

FRIDAY AFTERNOON AT 3:20

Pupin 301

(K. G. MCKAY presiding)

Photoconductivity; Luminescence; Semiconductors

SC1. A Theory of Photoconductivity of Zinc Oxide.* DONALD A. MELNICK AND DOUGLAS M. WARSCHAUER, *University of Pennsylvania*.—The photoconductivity of compressed and sintered zinc oxide has been found to be described by a bimolecular process of time constant of the order of an hour or more, plus a monomolecular process of time constant of the order of minutes. Shorter processes of very small amplitudes also exist. A model has been devised to explain this phenomenon. The minute process is assumed to be a quasi-thermal readjustment between the excited electrons in the conduction band and a band of levels, which also appear in conductivity measurements, about 0.6 or 0.7 ev below the conduction band. The slower process is assumed to be connected with a bimolecular recombination between electrons in the 0.7 ev band and trapped holes, which can have the time constant observed. Since the equations involved are not linear, an approximate method of solution is employed. The equations are set up in such a form that the two processes are separated, with the bimolecular part appearing as a slowly varying term in the faster process. Parameters calculated from the decay curve are then used to calculate the rise curve. The calculated curves give the expected agreement with the experimental data.

* This work was partly supported by the ONR.

SC2. On the Theory of Noise in Photoconductors. RICHARD L. PETRITY, *Catholic University of America*.—The existing theory of the fluctuation in the conductivity of a photoconductor is extended by considering both the number of conduction electrons, $N(t)$, and the number of quanta in the radiation field, $M(t)$, to be random variables, constituting a two-dimensional Markoffian random process. The model used for the photoconductor consists of two energy levels separated by $E=h\nu$ and we assume $h\nu \gg kT$ and neglect effects of the

Pauli principle. The radiation field exchanges energy of $h\nu$ with both the photoconductor and the surrounding heat bath. The power spectrums $S(N)$ and $S(M)$ have been calculated. The results indicate that $S(N)$ depends principally on the lifetime of an electron in the conduction band. $S(M)$ is dependent upon the relative strength of the coupling of the field with the heat bath and with the photoconductor (strong coupling meaning a large transition probability for absorption of a light quantum). In the limit of very weak coupling with the heat bath $S(M)$ has the same character as $S(N)$. In the limit of strong coupling with the heat bath, $S(M)$ differs from $S(N)$ and depends principally on the coupling between the radiation field and heat bath.

SC3. Electron Mobility in CdS. J. W. MacArthur,* *Rensselaer Polytechnic Institute.*—Photoconduction pulses were obtained in CdS by means of α-particle bombardment, and the rise times of these pulses were measured by means of a shorted coaxial stub technique. From the rise times the corresponding mobility values were calculated. The pulses were found to lie in two rough groups: small or normal pulses, corresponding to quantum efficiencies less than 100 percent, and large or amplified pulses showing evidence of current amplification or "secondary photoemission," i.e., quantum efficiencies greater than 100 percent. The normal pulses had a rise time of the order of 4×10^{-8} sec. in the setup used, i.e., the mobility was about $b_n=300$ cm²/volt sec. The amplified pulses had a rise time nearer to 3×10^{-7} sec under the same conditions, i.e., $b_a=40$ cm²/volt sec.

* Now at Marlboro College, Marlboro, Vermont.

SC4. Impedance Measurements on PbS Photoconductive Cells. E. S. Rittner and F. Grace,* *Philips Laboratories.*—It has been postulated[1] that in PbS photoconductive cells the intercrystalline contacts between *n*- and *p*-type material constitute a controlling influence on the dark resistance and photosensitivity. The most direct evidence yet advanced in support of this hypothesis is Chasmar's[2] observation that the parallel resistance decreases with increasing frequency, ostensibly due to capacitative shunting of the barriers. However, according to a theory of Howe[3] even a homogeneous resistor should exhibit a decrease in parallel resistance with frequency because of its distributed capacitance. A re-analysis of Chasmar's data in this light indicates that the Howe effect represents an alternative explanation of his results. Moreover, recent impedance measurements of our own on PbS photoconductive cells definitely favor the Howe explanation. Thus, it appears that the frequency dependence of the resistance can no longer be cited as evidence for the existence of barriers in PbS photoconductive cells. However, these results should not be construed as evidence against an *n*-*p* barrier picture, as the dispersion due to capacitative shunting of barriers may occur at high frequencies and hence be masked by the lower frequency dispersion due to distributed capacitance.

* Now at International Business Machines Corporation, Poughkeepsie New York.
[1] Sosnowski, Starkiewicz, and Simpson, Nature **158**, 28 (1946); **159**, 818 (1947).
[2] R. P. Chasmar, Nature **161**, 281 (1948).
[3] G. W. O. Howe, Wireless Engineer **12**, 291, 413 (1935); **17**, 471 (1940).

SC5. Injected Light Emission from Silicon Carbide Crystals. K. Lehovec, C. A. Accardo, and E. Jamgochian, *Signal Corps Engineering Laboratory.*—Previously[1] experiments were described on light emission from a blue silicon carbide crystal when current passes over a *p*-*n*-boundary in forward direction ("injected light emission"). We shall report investigations of injected light emission from other silicon carbide crystals, including pale green ones. Spectral distribution and decay time of the emitted light vary considerably, presumably due to presence of various activator impurities. The colors of light emission mainly noticed at room temperature were green and yellow, respectively. Efficiency of green light emission from a pale green crystal increased strongly with decreasing temperature, according to the equation: $2\times10^{-8}\exp(1370/T)$ light quantum emitted per electron passing through the crystal. Light emission from a dark blue silicon carbide crystal was found at voltages ≥1.8 volts at the *p*-*n*-barrier. This voltage is slightly less than the $h\nu/e$-value corresponding to the longest wavelength of the emitted light. The current through the barrier of this crystal seems to consist of two parts: one which is not rectified and does not contribute to light emission (conduction on impurity level?) and another which is rectified and leads to light emission (injection over the barrier).

[1] Lehovac, Accardo, and Jamgochian, Phys. Rev. **83**, 603 (1941).

SC6. Color Center Formation in Plastically Deformed KCl. E. Burstein, P. L. Smith, and J. W. Davisson, *Naval Research Laboratory.*—The effect of plastic deformation on color center formation in alkali halides, first investigated by Przibram, is being investigated in further detail. In KCl, as is well known, room temperature *x*-irradiation of annealed crystals yields the *F*-band, a weak *M*-band, and the *V*-band. Optical bleaching of the *F*-band increases the *M*-band and leads to the formation of the *R*- and *N*-bands. However, a short subsequent *x*-irradiation removes the *R*- and *N*-bands and returns the crystal essentially to its condition before optical bleaching of the *F*-band. *X*-irradiation of plastically deformed crystals, on the other hand, forms the *R*- and *N*-bands directly as well as new bands at 3400A and 2400A in the ultraviolet. Further, the extent of color center formation is enhanced in moderately deformed crystals, but is decreased in crystals which have been subjected to a strong plastic deformation, as in the case of KCl powder which is highly compressed to produce a transparent body. This investigation is now being extended to other alkali halides and to color center formation at low temperatures.

SC7. Investigation of the Thermoluminescence of Calcium Fluoride Colored by X-Ray Irradiation. John J. Hill and Jack Aron, *Lewis Laboratory, NACA* (introduced by G. Groetzinger).—The bleaching of CaF_2 crystals colored by irradiation with x-rays was studied by observing the spectral distribution of the radiation emitted during heating as a function of time and temperature. The monochromator of a Beckman spectrophotometer was equipped with an automatic scanning device and used in connection with a 5819 photomultiplier tube as a sensitive recording spectrometer. In the spectral range between 320 and 650 mμ, fifteen bands (*A* to *O*) were observed with peaks at 343, 365, 371, 379, 381, 415, 427, 437, 457, 478, 489, 522, 535, 543, and 574 mμ, about half of which have not previously been reported, possibly on account of their weak intensity. Consistent with the view that the radiation detected is connected with a decay process, the bands *E*, *F*, and *H*, which show a rather low intensity initially disappear at a slower rate than bands *I*, *J*, and *K* which show at first a much larger intensity.

SC8. Measurement of Diffusion in Germanium by Means of $p-n$ Junctions. W. C. Dunlap, Jr., *General Electric Research Laboratory.*—As pointed out in a recent letter,[1] the formation of a $p-n$ junction by the diffusion of an impurity into a semiconducting crystal can be used to study diffusion. Etched samples of single-crystal germanium were heated with the impurity, usually present as an evaporated film or as a vapor. Amounts of impurity of the order of a few micrograms were used to minimize alloying effects. Samples were ground off at an angle of 5 or 10° and tested for *p*- or *n*-type character using a thermoelectric or rectification probe. Diffusion distances ranging from 0.1 to 20 mil were measured. *N*-type germanium with $\rho<1$ ohm cm was used for the acceptor elements to minimize heat treatment effects. Preliminary values for the diffusion coefficients of six elements were obtained between 600° and 900°C. These are, for 900°C: donors, antimony 2×10^{-10} cm²/sec, arsenic 2×10^{-10}, phosphorus 8×10^{-11}; acceptors, zinc 1×10^{-11}, gallium 3×10^{-12}, indium 2×20^{-13} cm²/sec. The activation energy for antimony is about 2.5 ev. This quantity appears to increase slightly for the more slowly diffusing elements.

[1] R. N. Hall and W. C. Dunlap, Jr., Phys. Rev. **84**, 467 (1950).

SC9. Comparison of $p-n$ Junctions and Radioactive Tracers for Measurement of Diffusion. D. E. Brown and W. C. Dunlap, Jr., *General Electric Research Laboratory.*—Quantitative comparison has been made of the measurement of diffusion by the $p-n$ junction method and by the method of radioactive tracers, using antimony 124. Samples of p-type germanium were prepared by grinding both sides flat to a high precision using a special grinder. A film of antimony was applied by evaporation, and the metal diffused into the germanium a distance of a few mils. Surface layers were ground off on the same grinder used for preparation of the surfaces, and the activity of the powder ground into sheets of emery paper measured with a scintillation counter. The $p-n$ characteristic of each new surface produced was also checked by a thermoelectric probe. The diffusion coefficient for antimony at 900°C from the tracer method was 2.1×10^{-10} cm²/sec, from the $p-n$ junction method 1.6×10^{-10} cm²/sec. The radioactive tracer method is considerably more time-consuming than the $p-n$ junction method for studying diffusion in germanium, but can, unlike the $p-n$ junction method, be used for elements that can be obtained pure in radioactive form but which do not act as donor or acceptor in germanium.

Friday Evening at 7:00

Grand Ballroom, Hotel New Yorker

(C. C. Lauritsen and M. W. Zemansky presiding)

Banquet of the APS and the AAPT

After-dinner speakers: **O. E. Buckley,** *Bell Telephone Laboratories,* and **R. E. Peierls,** *University of Birmingham.*

Saturday Morning at 10:45

Pupin 428

(Arthur Roberts presiding)

Interactions of Mu-Mesons and Electrons

T1. An Improved Technique for μ-Meson Capture Measurements. J. W. Keuffel, F. B. Harrison, T. N. K. Godfrey, and Geo. T. Reynolds, *Princeton University.**—The apparatus previously described[1] for the measurement of mean lifetimes of negative μ-mesons has been modified by using distributed amplifiers, an improved chronotron timing circuit, and a liquid scintillation counter with better light collection. As a result, the timing uncertainty has been reduced to about 2×10^{-9} sec and the counting rates have been improved so that a 10 percent statistical accuracy can be achieved in about a week's run at sea level. When the decay curves of several elements were examined with improved time resolution, a short-lived component ($\tau\sim4-8$ mμsec) was found, which has been identified by a series of auxiliary experiments as caused by neutrons from proton-induced stars; the delays are produced by the time of flight of neutrons of a few mev as they diffuse out of the large (50–100 kg) target or the Pb above it. Errors from this effect, which were present in our earlier results, can be eliminated by rejecting counts delayed less than 30 mμsec, and by using a minimum of Pb in the counter telescope.

* Supported by the joint program of the ONR and AEC.
[1] Harrison, Keuffel, and Reynolds, Phys. Rev. **83**, 680 (1951).

T2. Capture Probabilities of μ-Mesons in Heavy Elements. F. B. Harrison, J. W. Keuffel, T. N. K. Godfrey, and Geo. T. Reynolds, *Princeton University.**—Our latest experimental results for the mean life of negative μ-mesons in heavy elements are: Sb, 80±9 mμsec; Hg, 58±4.7; Pb, 72±5.2; Bi, 63±8. The Wheeler theory, with $Z_0=10.3$ (based on the results for the light elements), gives about 25 mμsec for Hg, Pb, and Bi—a discrepancy of about a factor of three in the case of Pb. Kennedy's modification of the Wheeler theory (see following abstract) predicts 6.1 for the ratio of capture probabilities in Pb and Ca. This gives a mean life ratio of 5.3; the best experimental value is 4.1. The difference between the figures for Hg and Pb, which is thought to be statistically significant, is also qualitatively predicted by Kennedy. The mean life measurement previously reported for μ^--mesons in Sb[1] was affected by a systematic error because of the "short component" discussed in the preceding abstract. We estimate that the Cu value of 122±14 mμsec was not much affected.

* Supported by the joint program of the ONR and AEC.
[1] Harrison, Keuffel, and Reynolds, Phys. Rev. **83**, 680 (1951).

T3. A Theory of μ-Meson Capture. J. M. Kennedy, *Princeton University.**—The rate of absorption of negative μ-mesons in lead and in calcium has been calculated, assuming that the underlying reaction is of the charge exchange type described by Wheeler.[1] A shell model of the nucleus was used in making explicit calculations of the various nuclear matrix elements. The ratio of the absorption rate in lead to that in calcium is 6.1, in contrast to the value 14.3 predicted by Wheeler's theory. Another consequence of the nuclear model is that the absorption rate in mercury should be appreciably larger than that in lead, in spite of its smaller Z. These results are in fair agreement with the measurements of Harrison, Keuffel, Godfrey, and Reynolds, given in the preceding abstract. The coupling constant for the charge exchange reaction is $g\sim3\times10^{-49}$ erg cm³. This is approximately the same as the value of the β-decay coupling constant obtained from the decay of the neutron.

* Supported by the joint program of the ONR and AEC.
[1] J. A. Wheeler, Revs. Modern Phys. **21**, 133 (1949).

T4. An Experiment to Detect Pair-Production by Electrons.* N. S. SHIREN† AND R. F. POST,‡ *Stanford University.*—25-Mev electrons from a linear electron accelerator have been used in an experiment to detect direct pair production by electrons. Care was taken to obtain a beam uncontaminated by x-rays. The targets used were thin enough to make indirect effects negligible. The experimental method consisted of the identification of 511-kev annihilation radiation produced by positrons in a Be stopper placed at various angles with respect to the beam incident on the target. Identification was accomplished by using a "positron counter" described elsewhere,[1] which used NaI scintillation counters and operated by establishing the simultaneity, 180° angular correlation, and energy of the radiation from the stopper. Using a 0.006-inch Al target, measurements at 25° and 35° indicated the presence of positrons, but in an amount not statistically significant compared to background. However, from these data a statistically significant limit on the cross section may be deduced. Depending on the angular distribution assumed for the positrons, an upper limit is found for the total cross section which is equal to or less than theory.[2]

* Work supported by the ONR.
† Now at Columbia University, Hudson Laboratories, Dobbs Ferry, New York.
‡ Now at the University of California, Berkeley, California.
1 R. F. Post, Phys. Rev. **83**, 886 (1951).
2 H. J. Bhabha, Proc. Roy. Soc. (London) **A152**, 559 (1935).

T5. Energy Loss of 15-Mev Electrons.* A. O. HANSON, E. L. GOLDWASSER, AND F. E. MILLS, *University of Illinois.*—A 15.7-Mev electron beam from the University of Illinois 22-Mev betatron was incident upon absorbers of Ve, C, Al, Cu, Ag, and Au, each with a thickness of about 1 g/cm². The energy of the electrons after passing through any chosen foil was analyzed by use of a 70° magnetic spectrometer. The resolution of the entire apparatus was limited by the initial beam width and by the regulation of the magnetic field, to 20 kev for 15-Mev electrons. The observed distributions of energy loss for light elements was found to be in good agreement with the calculations of Landau[1] corrected for polarization effects by use of Fermi's expression for extreme relativistic velocities.[2] The most probable energy loss in kev may then be written as $(\Delta E)_\rho = 153.7D(Z/A)[19.43 + \ln(D/\rho)]$, where D is the surface density of the foil in g/cm² and ρ is the volume density of the material in g/cm³. The interpretation of the energy losses and struggling in the case of the heavier elements is much more complicated.

* Work supported in part by ONR.
1 L. Landau, J. Phys. (U.S.S.R.) **8**, 201 (1944).
2 E. Fermi, Phys. Rev. **57**, 485 (1940).

T6. Energy Loss of 2-Mev Electrons.* F. E. JABLONSKI,† B. WALDMAN, AND W. C. MILLER, *University of Notre Dame.*—The energy distribution of electrons passing through thin aluminum foils has been studied. The source of the 2-Mev electrons was the Notre Dame electrostatic generator. The energy of the incident electrons was constant to within 5 kev. A 90-degree magnetic spectrometer was used to analyze the transmitted beam. The resolution of the spectrometer was approximately 20 kev. Aluminum foils ranging in thickness from 3 to 180 mg/cm² were studied. The most probable energy loss is slightly less than that predicted by Landau.

* This work has been partially supported by the joint program of the ONR and AEC.
† Now at Naval Research Laboratory, Washington, D. C.

T7. Lower Electron Energy Losses in Zinc Oxide. OLIVE G. ENGEL, *National Bureau of Standards.*—A first approximation to the solution of the problem of obtaining cross sections for the energy losses of 30,000-volt electrons on passing through a thin edge of a zinc oxide crystal is made by assuming that scattering takes place from single ions in the lattice. The values of the expected losses are taken from spectroscopic data with the exception of that resulting from the transition of an electron from the oxide ion to the zinc ion. This loss is approximated by a method similar to that used by Seitz, but polarization energy and repulsive potential neglected by Seitz are taken into account. Cross sections for the transitions are found for a small scattering angle. The expression employed is derived by using the scattered amplitude found by Massey for collision of an electron with an atom.

SATURDAY MORNING AT 9:30

Pupin 301

(J. H. VAN VLECK presiding)

Invited Paper

U1. The Determination of Nuclear Masses from Microwave Spectra. STANLEY GESCHWIND, *Columbia University.* (30 min.)

Nuclear Masses; Magnetic Resonance; Radioactive Nuclei

U2. Masses of Pb^{208}, Th^{232}, U^{234}, and U^{238}.* G. S. STANFORD, *Wesleyan University*, H. E. DUCKWORTH, *Wesleyan University and McMaster University*, B. G. HOGG, AND J. S. GEIGER, *McMaster University.*—The following packing fraction differences (all $\times 10^4$) have recently been determined or redetermined, $Pb^{207}-Ba^{138}$: $\Delta f = 5.62 \pm 0.05$, $Th^{232}-Sn^{116}$: $\Delta f = 10.058 \pm 0.03$, $Sn^{116}-Ni^{58}$: $\Delta f = 2.647 \pm 0.015$, $Ni^{58}-Si^{29}$: $\Delta f = 3.07 \pm 0.02$, $U^{234}-Sn^{117}$: $\Delta f = 10.008 \pm 0.025$, $Sn^{118}-Co^{59}$: $\Delta f = 2.99 \pm 0.02$, $U^{238}-Sn^{119}$: $\Delta f = 10.187 \pm 0.025$. Using $H^1 = 1.008142 \pm 3$, $C^{12} = 12.003804 \pm 17$, $Si^{28} = 27.98579 \pm 4$ amu and appropriate transmutation data, one deduces from these and other mass differences previously reported from our laboratory, that $Pb^{208} = 208.0434 \pm 12$ amu, $Th^{232} = 232.1092 \pm 10$ amu, $U^{234} = 234.1133 \pm 11$ amu, and $U^{238} = 238.1234 \pm 10$ amu. Since these masses are related by more or less known disintegration data, they can be considered as a group and the individual values adjusted by imposing upon them the conditions[1] that $U^{238}-Pb^{208} = 30.0834 \pm 15$ amu, $U^{238}-Th^{232} = 6.0148 \pm 6$ amu and $U^{238}-U^{234} = 4.0112 \pm 2$ amu. The adjusted values so obtained are $Pb^{208} = 208.0424$ amu, $Th^{232} = 232.1093$ amu, $U^{234} = 234.1130$ amu, and $U^{238} = 238.1242$ amu, the probable errors being about 1 mMu. Typical mass spectra will be shown and comments will be made regarding the agreement between these and other existing mass data.

* Supported by the AEC, the Research Corporation, and the National Research Council of Canada.
1 G. T. Seaborg, private communication.

U3. Integral and Rational Numbers in the Nuclear Domain. ENOS E. WITMER, *University of Pennsylvania*.—Some years ago the writer proposed the idea that hc/e^2 is exactly 861, which is $41\times 42/2$. From the best and most recent value[1] of α^{-1}, hc/e^2 is slightly less than 861.023, which supports this idea quite well. The nuclear magnetic moments μ appear to be given by the equation $\mu = Ck$, where C is a constant and k is an integer or rational number with a small denominator. k is 1876 for the proton. There is much accurate data to support this statement. The extremely accurate ratios of the nuclear magnetic moments of certain isotopes make possible a very drastic test of this idea. Furthermore, it frequently happens that the k differences of isotopes are integers even when the k values are not integral but only rational. Also the masses of nuclei not subject to beta decay or K-capture appear to be an integral number of prouts. The prout is defined to be one-eleventh of the rest mass of the negative electron. Many of the nuclei subject to beta-decay or K-capture follow the integral rule. There are considerable data to support this.

[1] N. M. Kroll and F. Pollock, Phys. Rev. **84**, 594 (1951).

U4. Nuclear Magnetic Moment of Indium^{115}. YU TING, F. K. BIARD, AND DUDLEY WILLIAMS, *The Ohio State University*.—A nuclear magnetic resonance absorption line attributed to In^{115} has been observed in a saturated solution of indium nitrate in 30 percent nitric acid. Comparison of this line with the Sc^{45} line observed in $ScCl_3$ in the same magnetic field leads to the frequency ratio $\nu_{In}/\nu_{Sc} = 0.902292 \pm 0.000010$, where the indicated uncertainty is a measure of the internal consistency of the data, and the possibility of systematic errors as large as ± 0.000050 cannot be completely excluded. The observed ratio ν_{In}/ν_{Sc} used in conjunction with Lindstrom's value $\nu_{Sc}/\nu_{proton} = 0.242939 \pm 0.000003$ and the recent value $\mu_{proton} = 2.79268 \pm 0.00006$ nm leads to a value $\mu_{In} = 5.50945 \pm 0.00011$ nm when nuclear spin $I = 9/2$ is assumed. This preliminary value for the In^{115} magnetic moment has not been corrected for diamagnetic effects of the extra-nuclear electrons nor for the slight paramagnetic effects of a magnetic catalyst ($Mn(NO_3)_2$) used in the sample. Further work is being done on samples not containing a catalyst. The value obtained in the preliminary work is higher than the value obtained in molecular beam experiments.

U5. The Nuclear Gyromagnetic Ratio of Vanadium 50. H. E. WALCHLI, W. E. LEYSHON, AND F. M. SCHEITLIN, *Oak Ridge National Laboratory*.*—The nuclear gyromagnetic ratio of vanadium 50 has been determined in a nuclear induction spectrometer. An electronically regulated electromagnet maintained a field homogeneous to 0.1 gauss over the sample volume. Frequency measurements were made using a BC-221 frequency meter calibrated with an external 100 kc crystal controlled oscillator and checked against WWV. The sample consisted of 271 mg of vanadium as $VOCl_3$ of which 10 percent was V^{50}. Measurements at three values of magnetic field gave the following preliminary ratio:

$$\nu(V^{50})/\nu(D^2) = +0.649530 \pm 0.00007.$$

The sign of the moment was determined to be positive by direct comparison with Rb^{85} and Cl^{35}. Using a value of 2.7926 nm[1] for the proton moment and Levinthal's deuteron-to-proton ratio,[2] the nuclear gyromagnetic ratio for vanadium 50 becomes +0.55707. New frequency ratios, V^{50}/Rb^{85}; V^{50}/Cl^{35}; Rb^{85}/Cl^{35}; Rb^{85}/H^1; and Cl^{35}/H^1 will be reported.

* This paper is based on work performed for the AEC by Carbide and Carbon Chemicals Company, a Division of Union Carbide and Carbon Corporation, Oak Ridge, Tennessee.
[1] Sommer, Thomas, and Hipple, Phys. Rev. **80**, 487 (1950).
[2] E. C. Levinthal, Phys. Rev. **78**, 204 (1950).

U6. High Frequency Lines in the hfs Spectrum of Cesium. J. E. SHERWOOD, HAROLD LYONS, R. H. MCCRACKEN, AND P. KUSCH, *National Bureau of Standards*.—A brief account is given of the atomic beam magnetic resonance apparatus which is being developed at the National Bureau of Standards as a possible time standard in the microwave region.[1] The beam gear is essentially a Rabi[2] type apparatus, except for details. Permanent magnets are used for deflection together with a weak C field of the order of a few oersteds. A quartz oscillator-multiplier system is used as a stable exciting source and for precise frequency measurement. At present, a short path length of approximately one cm is used giving the expected Q of the order of 300,000 at 9192 Mc. Results are confined to experiments with cesium, for which the variation with magnetic field of some of the high frequency lines in the ground state hfs will be given. A new value is obtained for ν_0, the line frequency at zero magnetic field. This directly measured value lies between previously announced[3,4] values and outside their limits of error.

[1] P. Kusch, Phys. Rev. **76**, 161 (1949).
[2] J. M. B. Kellogg and S. Millman, Revs. Modern Phys. **18**, 323 (1946).
[3] P. Kusch and H. Taub, Phys. Rev. **75**, 1477 (1949).
[4] Roberts, Beers, and Hill, Technical Report No. 120, June 6, 1949. Research Lab. of Electronics, M.I.T.; Phys. Rev. **70**, 112 (1946).

U7. Magnetic Moment of Helium in the Metastable $^3S_1$ State by Atomic Beam Method.* G. L. TUCKER, V. W. HUGHES, E. H. RHODERICK, AND G. WEINREICH,† *Columbia University*.—A comparison has been made of the gyromagnetic ratio of the two-electron system in helium in the metastable $^3S_1$ state with that of the one-electron system in the ground state of hydrogen. The atomic beam magnetic resonance method was used and the atoms were made to traverse almost identical paths in the magnetic field.[1] With fields between 400 and 500 gauss the lines $m_J = \pm 1 \rightarrow 0$ of helium and $F, m_F = 1, 0 \leftrightarrow 1, -1$ of hydrogen were measured alternately. Using the Breit-Rabi formula for hydrogen and recent values[2] of g_I and $\Delta\nu$ we find $g_J(\text{He}, {}^3S_1)/g_J(\text{H}, {}^2S_{\frac{1}{2}}) = 1.000001 \pm 0.000025$. Using $g_J(\text{H}, {}^2S_{\frac{1}{2}})^3 = 2(1.0011275 \pm 0.000013)$ gives

$$g_J(\text{He}, {}^3S_1) = 2(1.001129 \pm 0.000028).$$

Precision was limited principally by field inhomogeneities and by field drift during approximately 15-minute periods between gases. Further measurements are in progress.

* Supported in part by ONR contract.
† AEC predoctoral fellow.
[1] For production and detection of a beam of metastable helium atoms see V. Hughes and G. Tucker, Phys. Rev. **82**, 322 (1951).
[2] H. Taub and P. Kusch, Phys. Rev. **75**, 1481 (1949); A. G. Prodell and P. Kusch, Phys. Rev. **79**, 1009 (1950). Uncertainties in these numbers do not limit our precision.
[3] Koenig, Prodell, and Kusch, Phys. Rev. **83**, 687 (1951).

U8. Measurement of Short β-Decay Lifetimes. R. N. THORN, R. W. WANIEK AND R. B. HOLT, *Harvard University*.—A method for measuring the lifetimes of isotopes extremely unstable to β-decay is described. These isotopes are produced in the bombardment of light elements by the internal proton beam of the Harvard fm cyclotron. The decay particles are detected by a crystal, Lucite probe, and photomultiplier arrangement. The target is located about four inches directly below the detecting crystal. Because of the focusing action of the magnetic field, most of the decay particles enter a cylindrical shaped anthracene crystal lodged in a slotted hole at the end of the Lucite rod. The Lucite pipe is enclosed in a vacuum-tight tube and transmits the light signal to a photomultiplier outside the cyclotron tank. The signal is fed from the photomultiplier to a cathode follower and from there to a linear amplifier in the control room. The pulses from the discriminator output go into an integrating circuit; the resulting current is registered on linear roll paper by a fast recorder. All circuits are left on continuously. The target is irradiated, the cyclotron is turned off, and the excitation is observed. By this method, lifetimes shorter than one-tenth of a second are measured.

U9. Preliminary Results from the Measurement of Short β-Decay Lifetimes. R. W. WANIEK, R. N. THORN AND R. B. HOLT.—With the arrangement described in the previous communication, measurements were taken by using a carbon plate as a target. Runs were made at 12 different proton energies chosen in the range between 20 and 110 Mev by varying the distance of the target from the center of the cyclotron tank. Due to the occurrence of simple and spallation reactions, a variety of modes of disintegration was observed. By pulse-height analysis and varying the time of irradiation, additional discrimination was obtained. Previously known lifetimes as well as several new ones appeared with great consistency over various bombarding energies. Work is underway to correlate these results with the data obtained using other light elements as targets. preliminary results will be given at the meeting.

U10. Gamma-Radiation of C^{10}.* R. SHERR AND J. GERHART, *Princeton University.*—The gamma-ray spectrum of C^{10} produced by the $B^{10}(p, n)$ reaction has been examined with a NaI scintillation spectrometer. In addition to 511 kev annihilation radiation, gamma-rays of energy 720 ± 15 kev and 1045 ± 20 kev were observed. The photopeak of the 1045-kev radiation is superimposed on a continuous distribution of hard radiation which was found also in C^{11}, Ne^{19}, and A^{35}. Absence of a significant Z dependence on absorbing the positrons in different materials, and the fact that the hardness increases with positron energy suggest that the continuous radiation is to be attributed to annihilation of positrons in motion. The intensities of the 720 kev and 1045 kev lines correspond to (1.0 ± 0.1) and (0.021 ± 0.005) γ-rays per positron of C^{10}. From the known levels of B^{10}, these γ-rays correspond, respectively, to β^+ transitions to the first (713 kev) and second (1740 kev) excited states, the latter reaching the ground state by cascade through the former. The ratio of the intensities expected on the basis of the f-values for allowed transitions is 0.07. The possibility that the existence of the 1045-kev line may be evidence for an allowed $0\rightarrow0$ β^+ transition will be discussed.

* Supported by the AEC and Higgins Scientific Trust Fund.

U11. The Nuclear Spectrum of Ge^{77}. ALAN B. SMITH AND ALLAN C. G. MITCHELL, *Indiana University.**—The disintegration of Ge^{77} has been studied with the help of a magnetic lens spectrometer, coincidence counters, and scintillation counters. The beta-ray spectrum of Ge^{77} (12 hr) consists of three groups whose end-point energies are 2.196 Mev, 1.379 Mev, and 0.710 Mev. In addition there are 13 gamma-rays appearing in the product nucleus As^{77}, some of which are internally converted. By coincidence counting techniques it has been shown that the beta-ray of energy 2.196 does not go to the ground state but to an excited state 0.264 Mev above the ground state. The isomeric transition from the 59-sec to the 12-hr states of Ge^{77} has been shown to be accompanied by a gamma-ray of 0.380-Mev energy in competition with the well-known beta-ray transition to the ground state of As^{77}. A disintegration scheme will be proposed.

* Supported by the joint program of the ONR and AEC.

U12. Angular Correlation and Intensity of Inner Bremsstrahlung from P^{32} and RaE. T. B. NOVEY, *Argonne National Laboratory.*—The angular correlation between the beta-particles and co-emitted inner bremsstrahlung has been measured in RaE. As in the similar experiments with P^{32}, the agreement of the correlation with that predicted by the theory of Knipp and Uhlenbeck and Bloch is excellent. Absolute gamma- per beta-intensity measurements have also been made of the continuous gamma-distributions in P^{32} and RaE. The radiation was detected using a NaI(Tl) scintillation-counter arrangement of the type described by Madansky and Rasetti. Problems of escape peak intensities and contributions from Compton distributions at present limit the accuracy of the absolute intensities. Theoretical intensity distributions were calculated using the experimentally obtained beta ray spectra of P^{32} and RaE. The agreement with theory is satisfactory for P^{32}, but is not as good as reported by Rasetti and Madansky for RaE. The theoretical intensity for RaE is about one-third of that for P^{32} due to the abundance of lower energy beta-particles from RaE but the experimental gamma-intensity in RaE is about equal to that in P^{32}. A small amount of $K-x$ radiations was found superimposed upon the RaE gamma spectrum. The x-ray intensity was only a few percent of the continuous gamma-intensity. This is in disagreement with Bruner's value of four conversion electrons per (theoretical) gamma unless the electron emission occurs predominantly from outer shells.

SATURDAY MORNING AT 9:30

Schermerhorn 501

(A. PAIS presiding)

Theoretical Physics, II

V1. One-Three Gamma-Gamma Angular Correlation. G. B. ARFKEN, L. C. BIEDENHARN, AND M. E. ROSE, *Oak Ridge National Laboratory.*—In a nuclear cascade involving three or more gamma-rays it is both desirable and feasible to measure the angular correlation of non-adjacent gammas either to confirm the results of correlating consecutive gammas or to resolve possible ambiguities. The angular correlation functions[1] for the observation of the first and third gammas in a triple cascade have been calculated with the use of Racah coefficients for cases of physical interest.[2] Consideration was limited to dipole and quadrupole radiation. While the anisotropies tend to be somewhat less than those from the correlation of consecutive gamma-rays, they are easily detectable by present experimental techniques. In at least two pairs of hypothetical decay schemes (J values 0, 1, 1, 2 and 0, 2, 1, 1; $\frac{1}{2}$, $\frac{3}{2}$, $\frac{3}{2}$, 5/2 and $\frac{1}{2}$, 5/2, $\frac{3}{2}$,$\frac{3}{2}$) correlation of consecutive gammas can never distinguish between the two possibilities. Correlation of the first and third gammas removes the ambiguity.

[1] Biedenharn, Arfken, and Rose, Phys. Rev. **83**, 586 (1951).
[2] Arfken, Biedenharn, and Rose, Oak Ridge National Laboratory Report No. 1103.

V2. Angular Correlation of the Radiations from Deuteron Stripping Reactions. L. C. BIEDENHARN,* KEITH BOYER,† AND R. A. CHARPIE,* *O.R.N.L.*—The angular distribution from deuteron stripping reactions[1] has proved useful in determining the spin (J) and parity of nuclei formed in the reaction. When the orbital momentum transfer (l_n) is nonzero, however, J is not uniquely determined. If the nucleus emits subsequent radiation (say, a gamma), this radiation should be correlated with the deuteron beam direction. In practice, one would measure coincidences of the gamma-ray and the stripped protons (say) of measured energy in order to identify the emitting nuclear state.[2] By observing this correlation further information on J might be obtained. The most informative case of this correlation is also the simplest, namely where the target nucleus has zero spin ($j_i=0$), since this eliminates both the channel spin ambiguity and restricts us to a single ln. For this case, we find the rather simple answer that, under the same assumptions as in reference (1), the gamma is correlated with the direction of the (cms) recoil momentum, $\mathbf{k}_d-\mathbf{k}_p$, precisely as if the residual nucleus were formed by the resonance capture of the neutron from a plane wave directed along this axis, the angular distribution of the proton entering as a multiplicative factor only. The case $j_i\neq 0$ will be discussed.

* Oak Ridge Laboratory.
† Los Alamos Scientific Laboratory.
[1] S. T. Butler, Proc. Roy. Soc. (London), **A208**, 559 (1951).
[2] Experiments of this type, (d; p, γ), were recently reported by G. C. Phillips, N. P. Heydenberg, and D. B. Cowie (Abstract D7, Bull. Am. Phys. Soc. No. 7, 8 (1951)). Isotropy was found in the cases observed, however.

V3. On the Interaction Term in β-Decay Theory. R. H. GOOD, JR., *University of California, Berkeley.*—The interaction terms ordinarily discussed are $J_i=-(\psi_P\gamma^4\Omega_i\psi_N)(\psi_e\gamma^4\Omega_i\psi_\nu)$ where i, ranging from 1 to 5, indicates the scalar, vector, tensor, axial vector, or pseudoscalar interaction.[1] Introducing the charge-conjugate descriptions of the proton and electron so as to treat all the particles equivalently, one may also write $J_i=-(\phi_PC\gamma^4\Omega_i\psi_N)(\phi_eC\gamma^4\Omega_i\psi_\nu)$. Since $C\gamma^4\Omega_iC^{-1}$ is the transpose of $\gamma^4\Omega_i$ for the vector and tensor, and the negative of the transpose otherwise, it follows that any linear combination of the vector and tensor interactions is symmetric with respect to an interchange of either the heavy particles or the light particles, and that any linear combination of the other three is correspondingly antisymmetric. The interactions J_i', formed from J_i by interchanging ψ_N and ψ_ν, may be expressed linearly in terms of the J_i so that $J_i'=\Sigma A_{ij}J_j$.[1] By considering the eigenvalue problem for the transpose of this A matrix, one finds that the two-parameter interaction, $(12a+3b)J_1+3aJ_2+(2a+b)J_3+3aJ_4+3bJ_5$, is symmetric with respect to an interchange of either the charged or the uncharged particles and that the three-parameter interaction, $(-2c-e)J_1+(c-d+e)J_2+cJ_3+dJ_4+eJ_5$, is correspondingly antisymmetric. From these two symmetry arguments one may deduce the Wigner-Critchfield interaction.

[1] M. Fierz, Z. Physik **104**, 553 (1937).

V4. On Darling's Theory of Fundamental Length. P. R. ZILSEL, *University of Connecticut.*—The infinite-order partial differential equation which in Darling's theory[1] replaces the Dirac-Kemmer equation for a free particle can be transformed into the integral equation,

$$\int\{\gamma_\nu(x_\nu-x_\nu')+\omega^2k\}\epsilon(x-x')\psi(x')d^4x'=0, \qquad (1)$$

where $\epsilon(x)=0$ for $x_0^2-r^2\leqslant 0$, and

$$\epsilon(x)=(x_0/|x_0|)(16\pi^2\omega^3)^{-1}\delta[2\omega-(x_0^2-r^2)^{\frac{1}{2}}],\quad x_0^2-r^2>0. \qquad (2)$$

This form exhibits clearly the role of the time-like fundamental displacement, ω. It also indicates a connection between Darling's theory and Born's reciprocity principle.[2]

[1] B. T. Darling, Phys. Rev. **80**, 460 (1950).
[2] M. Born, Revs. Modern Phys. 21, 463 (1949).

V5. Information, Thermodynamics, and Life. JEROME ROTHSTEIN, *Signal Corps Engineering Laboratories.*—Complex heat engines with material and energetic intake, and control, sensing, and motor devices forming mechanical analogs of living things, are described in principle. Essential to operation is selection of a subset from the manifold of possible behaviors, i.e., acquisition of information (measurement) and response thereto by virtue of information (constraints) encoded in structural organization. Conventional engines parallel vital chemico-mechanical energy conversion; these parallel reproduction (conventional and novel types), heredity, self-repair, dietary selectivity, food storage, symbiosis, parasitism, disease, poisoning, irritability, attack and defense, possibly learning, and other "vital" or "mental" functions. Cascading structural complexity enhances behavioral complexity, including aggregation into analogs of metazoa or societies. For a finite number of unit designs (cells), aggregates may be limited by internal capacity to transport matter, energy, and information. Adaptability and recuperation apparently depend on internal redundancy. The second law of thermodynamics is not violated notwithstanding "disentropic" behavior; negative entropy of information generating it is balanced by entropy increase accompanying measurement when the information is acquired.

[1] J. Rothstein, Science **114**, 171 (1951).

V6. Theory of Discrimination and Reliability in Crowded Situations. ARTHUR E. RUARK, *The Johns Hopkins University.*—(1) Garner and Hake, among others, have studied the behavior of observers presented with any one of a number of signals (various loudnesses, in their case), under conditions such that it becomes difficult to distinguish a signal from its neighbors. An "absolute" judgment is involved. Curves can be drawn showing how the frequency of mistakes depends on the spacing between a signal and its neighbors. (Other significant quantities are also measured.) The problem arises, how shall the total body of desired signals, n in number, be spaced along the total range of loudnesses in order to optimize some desired quantity, such as the information rate, or the average reliability per signal? Average reliability is here defined as the sum of (Chance a signal occurs) times (Reliability when that signal occurs). This paper solves the problem, for the case of reliability (for the sake of simplicity), but the method is quite general. (2) Extension to the continuous case yields an equation for designing the actuating mechanism of any scale-instrument, such that the reliability of the readings will be a maximum, when the probability distribution of the input-variable is known.

V7. Super-Potentials in Covariant Theories.* RALPH SCHILLER AND JOSHUA GOLDBERG, *Syracuse University.*—In the general theory of relativity, the existence of Bianchi identities permits one to formulate the so-called "strong" conservation laws. These have the form of four-dimensional divergences of the "stress" tensor which vanish identically, even when the field equations are not satisfied. From this relation one can infer that it must be possible to write the "stress tensor" as the divergence of a skew-symmetric form. The Bianchi identities follow from the fact that the field equations are derivable from a variational principle and the general covariance of these equations. The "strong laws" must be similarly related to these properties of the theory. Through explicit use of the infinitesimal transformation law of the Lagrangian density, it has been possible to derive a general expression for these skew-symmetric forms, and for a wider class of theories than the general theory of relativity. We have only assumed that the field equations are derivable from a variational principle. The form of the infinitesimal transformation law for the field variables is general enough to include tensors and spinors.

* Supported by the ONR.

V8. Equations of Motion in a Covariant Field Theory.* JOSHUA GOLDBERG AND RALPH SCHILLER, *Syracuse University.*—The only theory known today in which the equations of motion are determined by the field equations is the general theory of relativity.[1] This interrelationship results from the covariance of the theory and more particularly from the so-called Bianchi identities and the nonlinearity of the field equations, leading to "strong" conservation laws. Because of these strong conservation laws, there exist certain surface integrals, without the need of introducing coordinate conditions or a special power expansion in c^{-2}, which vanish if the field equations are satisfied at least on the surface of integration, regardless of the shape of that surface. In the case of the gravitational theory, plus the Einstein-Infeld expansion, our surface integrals go over into theirs. This result was obtained with the help of the super-potentials discussed in the preceding abstract.

* Supported by the ONR.
[1] A. Einstein and L. Infeld, Can. J. Math. 1, 209 (1949).

V9. Time-Dependent Canonical Transformations.* PETER G. BERGMANN AND RALPH SCHILLER, *Syracuse University*.—A re-examination of the representation of time-dependent coordinate and gauge transformations shows that the corresponding canonical transformations can be set up most conveniently and without logical difficulties in a "parameter" formalism, in which the fourth coordinate appears as a quasi-dynamical variable. Such transformations are meaningful only in a phase space or Hilbert space (in quantum theories) in which the Hamiltonian constraint is satisfied along with any other constraints. We have shown that the so-called secondary constraints[1] (which arise when the commutators or Poisson brackets are formed between the primary constraints and the Hamiltonian) are closely related to the energy-momentum density of such a theory. This whole treatment permits one to tie a consistently four-dimensional representation of a covariant theory together with the canonical approach, which favors one time-like direction.

* Supported by the ONR.
[1] J. L. Anderson and P. G. Bergmann, Phys. Rev. 83, 1018–1025 (1951).

V10. General Relativity and Angular Momentum.* ROBB THOMSON AND PETER G. BERGMANN, *Syracuse University*.—The conservation law of angular momentum, both in nonrelativistic and in Lorentz-covariant theories, is based on the invariance of the theory with respect to homogeneous orthogonal (or Lorentz) transformations. In general relativity, such a transformation is meaningless, and what is left of the law of angular momentum must be contained explicitly in the powerful law of conservation of linear momentum density of general relativity. If spinors are introduced into general relativity, we have again the possibility of spin transformations and with them local Lorentz (Bein-) transformations. Examination shows that this transformation group does not lead to a true conservation law. However, the rate of change of the spin angular momentum is determined by an expression which, though not itself a true time derivative, is closely related to what ordinarily would be interpreted as the rate of change of the orbital angular momentum.

* Supported by the ONR.

V11. Statistical Mechanics in General Relativity. J. W. WEINBERG, *University of Minnesota*, AND G. E. TAUBER, *McMaster University, Ontario*.—Relativistic statistical mechanics has been found for particles interacting through gravitation. Canonical momenta p_μ are defined together with an invariant Hamiltonian $m(x,p)=[g^{\mu\nu}p_\mu p_\nu]^{\frac{1}{2}}$ by means of $dx^\mu/ds=(\partial m/\partial p_\mu)_x$. From $dp_\mu/ds=-(\partial m/\partial x^\mu)_p$ and its consequence $dm/ds=0$, one derives Einstein's geodesic law and the identity of m and the constant rest mass along any trajectory. The space of x^μ, p_ν, a sequence of ordinary phase spaces for each time and mass, admits an invariant n that reduces essentially to the usual density-in-phase near any point and in locally co-moving coordinates. The differential conservation law for the number of systems is expressed by Liouville's theorem $dn/ds=0$, as a consequence of which the energy density $T_{\mu\nu}(g)^{\frac{1}{2}}$ defined by the integral over p_μ-space of $np_\mu p_\nu$ satisfies the covariant conservation law. This result for $T_{\mu\nu}$ includes a representation of *all* equations of state relating invariant pressure p_0 to density ρ_{00}, that comply with relativistic restrictions on the motion of particles. On comparison, many equations of state proposed in astrophysics prove unacceptable. As a simple example, the case of the spherical cluster possesses in addition to the known $3p_0\leqslant\rho_{00}$, the new relativistic restriction, $4(dp_0/d\rho_{00})\leqslant 1+(p_0/\rho_{00})$.

V12. Thermal Equilibrium in General Relativity. G. E. TAUBER, *McMaster University, Ontario*, AND J. W. WEINBERG, *University of Minnesota*.—Binary collisions described by an invariant cross section can be introduced into the formalism of the preceding abstract to establish the H-theorem, $\partial S^\mu(-g)^{\frac{1}{2}}/\partial x^\mu=0$ for the entropy S^μ defined as the integral over p_μ-space of $np^\mu\ln(1/n)$. Thermal equilibrium requires detailed balancing which results in $n\alpha\exp(-mq^0-p_\mu q^\mu)$ for classical statistics. $(q^\mu q_\mu)^{-\frac{1}{2}}$ is essentially the temperature field, while $q^\mu(q^\nu q_\nu)^{-\frac{1}{2}}$ defines a velocity field for the mean motion at every point. Liouville's theorem then requires $q_{\mu,\nu}+q_{\nu,\mu}=0$. This theory reduces to Tolman's relativistic generalization of thermodynamics in those special cases where Tolman's work is applicable. For example, the limitations on $q^\mu(x)$ reduce to the rule that the temperature $\alpha(g_{44})^{-\frac{1}{2}}$ in the static, spherical cluster; and in nonrelativistic approximation they limit the mean velocity field to that of a rigid motion. For the axially symmetric cluster they describe the generalization of rigid rotation in a simple way permitting the use of integrable co-rotating coordinates for the interior. The field equations then reduce to those of the static case with the limitation that pressure and density depend on g_{44} alone and with the addition of a Coriolis field mixing differentials of angle and time in ds^2. These conclusions remain essentially unaltered in quantum statistics.

V13. Markoff Random Processes and the Statistical Mechanics of Time-Dependent Phenomena. MELVILLE S. GREEN, *University of Maryland*.—An attempt is made to develop the principles of a statistical mechanics of time dependent phenomena. It is asserted that the proper objects of study of such a theory are the grossly observable quantities considered as stationary random processes. The hypothesis suggested by Peirls and Richardson that these random processes are Markoffian is argued for. The Fokker Planck equation for these processes is derived by a generalization of a method of Kirkwood for Brownian motion. If $a_i i=1\cdots s$ are the gross variables, $W_0(a_1\cdots a_s)$, their equilibrium distribution, $W(a_1\cdots a_s, t)$, their distribution at time t, this equation is

$$\frac{\partial W}{\partial t}=\sum_{ij}\frac{\partial}{\partial a_i}\left\{-\left[v_i+\xi_{ij}\frac{\partial\log W_0}{\partial a_j}+\frac{\partial}{\partial a_j}\xi_{ij}\right]W+\frac{\partial}{\partial a_j}\xi_{ij}W\right\}.$$

The quantities v_i are the conditional mean rates of change of the a_i for fixed values of the a_i. The ξ_{ij} are related to the conditional auto-correlation of the rates. Reciprocal relations are derived for the ξ_{ij} which are generalizations of the Onsager reciprocal relations. An entropy of the distribution W is defined and shown always to increase.

V14. Brownian Motion Theory as a Tool in Statistical Mechanics. A. J. F. SIEGERT, *Northwestern University*.—The problem of evaluating

$$\rho(\mathbf{q}_0|\mathbf{q},\beta)=\sum_\nu\psi_\nu(\mathbf{q}_0)\exp(-\beta H)\psi_\nu(\mathbf{q})$$

for a Boltzmann system of N particles at temperature $T=1/k\beta$, where the functions $\psi_\nu(\mathbf{q})$ are orthonormal in a region $\Omega=V^N$ of $3N$-dimensional configuration ($\mathbf{q}$) space, and H is the Hamiltonian operator with potential energy $U(\mathbf{q})$, can be formulated as a problem of Brownian motion in $\mathbf{q}$-space, with β interpreted as a time and $|U(\mathbf{q})|\Delta t$ as absorption (or duplication) probability. This yields

$$\rho(\mathbf{q}_0|\mathbf{q},\beta)=\left\langle \exp\left[-\int_0^\beta U(\mathbf{q}(t))dt\delta(\mathbf{q}(\beta)-\mathbf{q})\right\rangle_{\text{Av}}$$

averaged over all Brownian motion paths which start at $\mathbf{q}_0$ and do not touch the surface of Ω. From this expression (or from an integral equation deduced by a simple counting argument) one obtains a more convenient form of the Goldberger-Adams[1] series. The average can also in principle be calculated exactly if contributions come only from the neighborhood of a point (solid) or a line in $\mathbf{q}$-space.

[1] M. L. Goldberger and E. N. Adams, II, J. Chem. Phys. (to be published)

Saturday Morning at 9:30

Havemeyer 309

(M. H. Hebb presiding)

Solid-State Physics (Non-Metals)

W1. Extinction Effects in Neutron Transmission of Polycrystalline Media.* R. J. Weiss, *Watertown Arsenal.*—The effects of primary and secondary extinction are considered for neutron transmission work in the diffraction energy region. It is shown that the grain size is the most important parameter affecting extinction in typical studies with the mosaic block size and the angular spread of the mosaic blocks of secondary importance. Experiments were performed to corroborate the theory, and criteria are set up to avoid extinction effects. It is shown how to determine mosaic block size and the angular spread of the mosaic blocks in large grain substances by using fine resolution near the last Bragg cut-off peak.

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

W2. The Diffuse Scattering of Neutrons and X-Rays.* David A. Kleinman, *Brookhaven.*—It appears that the principal possibility for directly measuring the frequency and polarization of the thermal vibrations (phonons) in a solid is by use of the temperature diffuse scattering of neutrons and x-rays. The important property of the temperature diffuse scattering is that measurements on the scattered radiation can fix the wave vector, frequency, and polarization of the phonons. Although for Bragg scattering of both neutrons and x-rays it is possible to treat the thermal vibrations as merely smearing out the scattering centers, the diffuse scattering should be treated quantum mechanically by considering the creation and annihilation of phonons. Under favorable experimental conditions the diffuse scattering will be due mainly to processes involving a single phonon. Since energy and momentum are conserved in these scattering processes, and since neutrons have very small energies compared to x-rays of the same momentum, there is a considerable difference in the diffuse scattering of neutrons and x-rays. The wave vector of the phonon is determined by the direction and the frequency of the phonon by the intensity of the scattered x-ray. On the other hand both the direction and energy of the scattered neutron must be measured to determine the phonon wave vector, but the frequency is then known from the conservation of energy without a measurement of the scattered intensity.

* Research carried out under contract with the AEC.

W3. Calculation of Energy Bands in Solids by the Integral Iteration Method.* M. Dank and H. B. Callen, *University of Pennsylvania.*—An investigation has been made into the applicability of the Kellogg-Collatz integral iteration method to the calculation of electronic energy levels in solids. Separability of variables is not required, hence the true lattice symmetry need not be sacrificed in favor of a spherical approximation to polyhedral zones. Also, the method is based on integral rather than differential equations, for which numerical calculations are considerably more convenient. A Bloch-type wave function is invariant under the appropriate integral transformations, so that the iterates of an initial approximation function of the Bloch form converge to the true wave function with the same wave vector. The speed of convergence depends on the ratio of the eigenvalues of the two lowest wave functions with the given wave vector in the reduced zone scheme and is therefore quite rapid. The method can be applied in either coordinate or momentum space. The three-dimensional iteration formula in the coordinate space scheme involves a modified Green's function characteristic only of the crystallographic form which is identical to the "lattice sum" of the scattering matrix formalism. A method for treating these sums will be discussed.

* Research supported by the ONR.

W4. Anisotropy of Thermal Expansion and Internal Stresses in Polycrystalline Graphite and Carbons. S. Mrozowski, *University of Buffalo.*—The anisotropic thermal expansion of microcrystals has been found to create considerable internal stresses in metals.[1] Much more pronounced effects of this kind are met in polycrystalline carbons, where the extremely large anisotropy of microcrystals is responsible for a number of properties characteristic to these materials. Heating an untreated carbon creates large stresses concentrated at the peripheries of crystallites, where they are attached to their neighbors by C–C valence bonds. These stresses constitute the main driving force promoting the growth of crystallites up to temperatures 2200°C (or even higher). When a heat-treated sample is cooled, the volume of crystallites decreases more than the apparent volume of the sample and as a result an unavoidable internal porosity (up to 8 percent) and internal stresses are formed. Since steady creep is absent (<2200°C),[2] the internal stresses are not relieved by plastic flow and remain locked in the material. The recently observed higher tensile strength of carbons at high temperatures[2] is one of manifestations of the reversible release of these stresses as the material is heated (and vice versa).

[1] F. P. Bowden, "Symposium on Internal Stresses in Metals," Institute of Metals, London, 1948.
[2] Malmstrom, Keen, and Green, Jr., J. Appl. Phys. 22, 593 (1951).

W5. Evidence for a Pressure Effect in Thin Films of LiF. Nathan Sclar and Henry Levenstein, *Syracuse University.*—Preliminary studies have been made on the dielectric properties of thin evaporated films. For LiF, the dielectric constant and the break-down field were measured as a function of film thickness. Thin film condensers were prepared by consecutive evaporations of aluminum on glass, dielectric on the aluminum, and finally aluminum on the dielectric. The dielectric constant was calculated from the measured capacitance of the condensers at 1000 c/s, while the thicknesses of the evaporated films were determined by multiple beam interferometry using white light. Thicknesses ranged from 440–2500A. All the dielectric constant values fall below those of the bulk material. Boswell[1] has recorded a change in lattice constant with crystallite size. He attributed this change to a pressure effect. By combining his data, the compressibility of LiF, and Mayburg's[2] data on the variation of dielectric constant with pressure, we deduce a fractional change in dielectric constant for the thin films which agrees in order of magnitude with the experimental results. This lends credence for the existence of a pressure effect in thin films.

[1] Boswell, Proc. Phys. Soc. (London) **A64**, 465 (1951).
[2] Sumner Mayburg, Phys. Rev. **79**, 375 (1950).

W6. Studies of Self-Diffusion in Graphite Using C[1] Tracer.* M. Feldman, W. Goeddel, and G. J. Dienes.—Self-diffusion in graphite was measured over the temperature range from 1835°C to 2370°C by observing the penetration of C^{14} tracer initially applied to one end of a graphite rod. The experimental data were found to be in agreement with a diffusion mechanism consisting of concurrent volume and grain boundary processes. Activation energies for both processes (E_V and E_B) could not be uniquely obtained from the data, however. An independent determination of either is required in order to evaluate the other. Assuming $E_V=160$ kcal/mole from recent work, it is calculated from the present experiments that E_B, the activation energy for grain boundary diffusion, is 110 kcal/mole.

* Based on studies conducted for the AEC.

W7. Instability Criteria for the Fracture of Solids. H. L. Smith, J. A. Kies, and G. R. Irwin, *Naval Research Laboratory*.—The development of instability for fast fracturing at the expense of stored elastic energy has been investigated, principally in sheets of transparent plastics, and for geometrically similar specimens has been found to contain a size effect. In fracturing a material one may describe the rate of doing work in terms of the quantity dW/dA where dW is the work increment and dA the increase in fracture area. In a tensile stress field there is a rate of strain energy release accompanying fracturing referred to as dE/dA. The critical point or the point of instability occurs in fast fracturing when $dE/dA \geqq dW/dA$. The use of this instability point permits one to predict a size effect in fracture which agrees with the experimental results obtained. The excess of elastic energy not used in simple fast fracturing can be computed. This is available for other interesting processes, notably shattering.

W8. The Work to Create Fracture Surfaces in Methyl Methacrylate. Mark Bowman, Jr. and H. L. Smith, *Naval Research Laboratory*.—It has been shown that the rate dw/da, the energy absorbed per unit area of fracture surface is of primary importance in determining the stress at fracture in a brittle material. This quantity may be thought of as a combination of surface energy and work expended in plastic deformation of the material very close to the fracture surface. Direct experimental determination of dw/da for fast processes is generally not feasible. Computation of dw/da from the instability criterion used by H. Smith and others in the preceding paper reveals that for methyl methacrylate a value is obtained which is fairly independent of crack length. This is typical of brittle fracture and is contrary to typical results for materials such as aluminum foils. Such a computation permits a more critical evaluation of the embrittling effects of low temperatures than is afforded by standard impact test procedures, for example significant differences were found at 25°C, −10°C, and −40°C in dw/da, whereas Charpy impact tests failed to make distinctions in this range of temperatures.

W9. A Study in the Dynamics of Crystal Growth from a Supersaturated Solution. G. C. Krueger, *University of Maine*,* and C. W. Miller, *Brown University*.—An experimental investigation of the concentration field during crystallization is made using an improved modification of W. F. Berg's interference technique.[1] $Na_2S_2O_3 \cdot 5H_2O$ is crystallized at 23°C, concentrations between 40 percent and 55 percent. Graphing the positions of the growing faces *versus* time indicates, in all cases, a uniform rate of growth with occasional abrupt changes. These discontinuities were in general correlated with changes in the perfection of the growing face, the disappearance of a region of poor growth being associated with a decreased rate, whereas the appearance of an imperfection led to a higher rate. A minimum of concentration is observed near the face center, corroborating previous investigations with $NaClO_3$.[1] A diffusion coefficient of 1.26×10^{-5} cm²/sec was calculated for $Na_2S_2O_3$ corresponding to 0.80×10^{-5} cm²/sec extrapolated from J. D. R. Scheffer's data.[2] There is no strict correlation between maximum, minimum, or average concentration at a crystal face and its rate of growth. It appears that the variations in concentration revealed by interferometer maps are to be interpreted as a consequence of solution depletion occasioned by the crystal's growth.

* The experimental work was done at Brown University.
[1] W. F. Berg, Proc. Roy. Soc. (London) **164A**, 79 (1938); S. P. F. Humphreys-Owen, Proc. Roy. Soc. (London) **197A**, 218 (1949).
[2] J. D. R. Scheffer, Z. physik. Chem. **2**, 397 (1888).

W10. Comparative Elastic Studies of Single Crystals of the NaCl Type.* Lewis S. Combes, Stanley S. Ballard, and Kathryn A. McCarthy, *Tufts College*.—Data on Young's modulus, apparent elastic limit, and modulus of rupture have been obtained for five crystals: sodium chloride, silver chloride, lithium fluoride, potassium chloride, and potassium bromide. All measurements were made on bars cut or cleaved from single crystals; each bar was supported as a simple beam and subjected to a flexural stress by loading at its center. Typical load-deflection curves will be shown for each crystal. In addition, measurements were made on a sodium chloride crystal with a silver impurity, Na(Ag)Cl. The apparent elastic limit for this sample was found to be 3.9×10^7 dyne cm^{-2} as compared to a previously reported[1] value of 2.4×10^7 for sodium chloride. The modulus of rupture for this sample was 9.8×10^7 dyne cm^{-2} as compared to 3.9×10^7 for sodium chloride.

* This work has received support from the Permanent Science Fund of the American Academy of Arts and Sciences.
[1] Combes, Ballard, and McCarthy, J. Opt. Soc. Am. **41**, 215–222 (1951).

W11. An Electronic Instrument for the Measurement of Crystal Anelasticity. R. D. Laughlin, *National Bureau of Standards*.—An instrument has been devised which makes it possible to measure the "Q" of a vibrating piezoelectric crystal during its free decay. The principle of operation is that of determining the time interval between any two selected voltage points on the exponentially decaying wave form. The circuit operation is as follows: The specimen is driven at its resonant frequency and then allowed to damp itself in free decay. The decaying vibrations are amplified in a linear amplifier to a level of approximately 100 volts peak and are rectified and filtered. The smoothed replica of the original wave form is fed into two separate Multiar type voltage comparator circuits. The first comparator circuit produces a timing signal to start a bistable multivibrator. The second comparator produces a timing signal to stop the multivibrator. The start and stop voltages are independently controlled by an external source. The rectangle produced by the bistable multivibrator is introduced into an electronic chronoscope to measure the time interval. The chronoscope gives the interval in milliseconds. A simple relation exists between the time interval, the voltage ratios, and the "Q." "Q's" have been measured as a function of temperature for a quartz bar in torsional oscillation at 36 kc. A preliminary estimate of the accuracy of measurements is 2 percent.

W12. Ferroelectricity in the Ilmenite Structure. H. C. Schweinler, *M.I.T.*—The ferroelectricity of the ilmenite structure minerals lithium tantalate and lithium niobate is studied theoretically, using the method recently introduced by Slater[1] for barium titanate. The metal ions are assumed to move in a potential which has small quartic terms as well as the usual quadratic terms, all satisfying the appropriate crystal symmetry requirements. This results in a slight dependence of the ionic-displacement polarizability of each metal ion on both the temperature and the polarization of the crystal. The local electric field strength is computed exactly for each ion by Ewald's method, and the internal field constants are given for a number of positions in a rhombohedral unit cell of axial angle $\alpha=56°$. The polarizabilities can be estimated from other crystal polarization data, leading to a spontaneous polarization below the upper Curie temperature T_0 of $2(T_0-T)^{\frac{1}{2}}\mu$ coul cm^{-2} (without electromechanical correction). It is found that (unlike the corresponding case in barium titanate) there are sizeable components of the oxygen dipole moments perpendicular to the total polarization, but these components produce a large field in the direction of the polarization at other ionic positions.

[1] J. C. Slater, Phys. Rev. 78, 748 (1950)

W13. High Temperature Susceptibility of Permanent Dipolar Lattices.* R. Rosenberg and M. Lax, *Syracuse University.*—The spherical approximation yields, for the susceptibility of permanent dipolar materials, a result which is valid at high and low temperatures.[1] For liquids at high temperatures this result agrees perfectly to terms of order T^{-3}, with the Onsager approximation[2] and the Van Vleck[2] exact treatment. In order to judge the success of the spherical approximation, it was therefore necessary to carry the exact treatment at high temperatures to the term of order T^{-4}. The sphericalization procedure is found to be more accurate than the Onsager treatment, and underestimates the susceptibility where Onsager overestimates it. In the exact solution for the polarization, the coefficient of T^{-n} is a combination of sums over certain types of dipole clusters which contain n dipoles at most. The clusters of n dipoles are simple open chains, producing essentially all the shape dependence, and therefore cancel out of the susceptibility. In contrast with the exact polarization, which contains all types of clusters, the spherical approximation includes the simple open chains and single-loop clusters only.

* This work supported in part by the ONR.
[1] M. Lax, Bull. Am. Phys. Soc. 26, No. 7, G2 (1951).
[2] J. H. Van Vleck, J. Chem. Phys. 5, 320 (1937).

W14. Multiple Scattering of Waves. II. The Effective Field in Dense Systems.* Melvin Lax, *Syracuse University.*—The multiple scattering of waves interacting with a system of particles is treated by a self-consistent approach. Scattering processes are described by operators that permit anisotropy, absorption, and creation. The scattering system may be randomly, partially, or completely ordered. The propagation constant k' of the coherent wave in the scatterer medium differs from the vacuum constant k by $(k')^2=k^2+4\pi ncf(\mathbf{k}', \mathbf{k}')$, where n is the scatterer density and f is an operator whose matrix elements $f(\mathbf{b}, \mathbf{a})$ represent the scattering amplitude in direction $\mathbf{b}$ for a wave incident in direction $\mathbf{a}$ on a single scatterer bound by the forces of its neighbors. The parameter c, defined by $cf(k', k')=\int \exp(-i\mathbf{k}'\cdot\mathbf{r})f\psi_e(\mathbf{r})d\mathbf{r}$, is a measure of the ratio of the effective field $\psi_e(\mathbf{r})$ to the average field. An integral equation is found for $\psi_e(\mathbf{r})$ with the help of a "quasi-crystalline" approximation. A variational expression is then found for c that becomes exact for point scatterers. A comparison is made of finite and infinite scattering systems. The extinction theorem is proven. The macroscopic viewpoint is found to be applicable to small systems whose size is large compared to the scatterer potential range, and the range of scatterer position correlations.

* This work supported in part by the ONR.

W15. Shape of a Two-Dimensional Crystal Minimizing the Surface Energy. John P. Nielsen, *New York University* and Boris Garfinkel, *Aberdeen.*—A crystal in equilibrium with its surroundings assumes a shape which minimizes the surface energy. For a two-dimensional crystal with a known energy density distribution of the peripheral surface, we may determine the bounding curve by solving an isoperimetric problem in the calculus of variations. If the crystal is isotropic with respect to the surface energy, the curve, of course, is a circle. If the crystal is anisotropic, a more complicated curve results from the solution of the Euler-Lagrange equations. In particular, if $\gamma=1+a\cos\phi$, where γ is the energy density, and ϕ the angle made by the tangent to the curve and a symmetry axis in a twofold symmetry crystal, the closed curve consists of a pair of parallel straight lines surmounted by a pair of semicircles. The curve is of class C', i.e., it has no corners. The same solution also holds for the so-called negative crystal, i.e., a hole within a crystal.

Saturday Morning at 9:30

McMillin

(C. C. Lauritsen presiding)

Invited Papers in Nuclear Physics

X1. The Nuclear Interactions of Pions of Energy near 70 Mev. J. Steinberger and A. Sachs, *Columbia University.* (30 min.)

X2. Production of Charged Pions by Protons. W. W. Havens, Jr., *Columbia University.* (30 min.)

X3. Disintegrations Produced by Monoenergetic 14-Mev Neutrons. T. W. Bonner, *Rice Institute.* (30 min.)

X4. Magnetic-Analysis Studies of Nuclear Energy-Levels. W. W. Buechner, *M.I.T.* (30 min.)

SATURDAY AFTERNOON AT 2:00

Pupin 301

(R. L. SERBER presiding)

Invited Paper

Y1. Nonlocal Field-Theory. R. E. PEIERLS, *University of Birmingham (England)*. (40 min.)

Meson Theory

Y2. Quantization of a Nonlinear Meson Theory. L. I. SCHIFF, *Stanford University*.*—Two distinct attempts at quantization of the nonlinear meson theory described earlier[1] have been undertaken. (1) The canonical transformation $\exp[i\int\phi_0(\mathbf{r})\pi(\mathbf{r})d\tau]$, where $\phi_0(\mathbf{r})$ is a *c*-number function that satisfies the classical field equation, separates the Hamiltonian into static and nonstatic parts that have simple interpretations in some cases. It can be used to treat the scattering of mesons by nuclei (I, Sec. XI), and to show that the result obtained classically in II is also valid in quantum theory if the nonlinear coupling function has a power form ($F=b\phi^m$). (2) The case treated in I can also be quantized approximately by neglecting the $(\nabla\phi)^2$ term in the Hamiltonian, so that the field becomes a set of uncoupled nonlinear oscillators, one for each point in space. This has the advantage that the nonlinearity is explicitly considered in the quantization, and the disadvantages that wave aspects are suppressed and it is difficult to correct for the neglected term. The method is being applied to a finite one-dimensional lattice as an example.

* Assisted in part by the joint program of the ONR and AEC.
[1] Phys. Rev. **84**, 1, 10 (1951); referred to here as I and II, respectively.

Y3. Applications of the Charge Independence Hypothesis to Meson Phenomena. KENNETH M. WATSON, *Indiana University*.—The hypothesis of charge independence for nuclear forces can be generalized to include an extensive class of meson-nucleon phenomena. Application of this principle has previously been made to meson scattering[1] and to meson production in nucleon-nucleon collisions,[2] for which no disagreement is found with presently available experimental results. The principle can also be directly applied to nucleon collisions in which several mesons are produced. Because of the symmetry properties with respect to transformations of charge states of the electric current vectors of mesons and nucleons in field theories, charge independence places certain restrictions on the various cross sections for photomeson production. The restrictions are somewhat complicated, but are nevertheless capable of being subjected to an experimental check. The charge independence principle can also be generalized to include heavy unstable particles, such as *V*-particles and τ-mesons. Here the theory makes predictions as to the charge states of these particles and to the relative rates of competing decay schemes.

[1] W. Heitler, Proc. Roy. Irish Acad. **51**, 33 (1946).
[2] K. M. Watson and K. A. Brueckner, Phys. Rev. **83**, 1 (1951).

Y4. Some Meson Contributions to the Photodisintegration of the Deuteron. M. H. FRIEDMAN, *University of Illinois*.—One of the difficulties encountered in calculating the cross section for the photodisintegration of the deuteron at high energies is the uncertainty of meson contributions to those channels which involve interaction of the nucleon spins with the electromagnetic field. A calculation has been carried out, treating the nucleons nonrelativistically, and using weak pseudovector coupling pseudoscalar meson theory. Processes in which mesons are exchanged between nucleons are not calculated explicitly. In the case of the electric disintegration, they are taken into account by Siegert's theorem. In the photomagnetic processes they would lead to the interaction momen-effects, which we here assume are small. In the approximation used (which assumes the nucleon kinetic energies are small compared to the meson energies involved) it is found that the only effect of the charge clouds about the nucleons is to make the magnetic moments dependent upon the frequency of the quanta. The static moments were subtracted out and replaced by the experimentally observed ones. The results show that for low energies the magnetic terms are still small compared to the electric. However, for energies of the order of 140 Mev, the magnetic terms become comparable with the electric and contribute appreciably to the cross section.

Y5. Stability of Neutral Scalar Heavy Mesons. H. P. NOYES, *University of Rochester*.—Salam's result[1] that *S*(*S*) and *PS*(*PS*) meson theories are renormalizable by contact interactions suggests that the calculation of the decay of spin zero heavy mesons into π-mesons and γ-rays should yield finite and unambiguous results. The process (1) $S\rightarrow PS+PS$ is logarithmically divergent but renormalizable by the contact interaction $(\chi+\delta\chi)G_sg_{ps}{}^2\Phi_s\varphi_{ps}{}^*\varphi_{ps}(\chi)$ where $\delta\chi$ cancels the divergence and χ is an empirical constant determinable from this lifetime. This interaction also contributes to (2) $S\rightarrow\gamma+\gamma$ in order $G_sg_{ps}{}^2e^2$. When χ gives a long lifetime for (1) it also cancels the imaginary part of the matrix element for (2) because of two *PS* mesons occurring as a real intermediate state. The sum of the remaining fifth order contributions is of opposite sign to the lowest order (G_se^2) matrix element. Consequently there exists a relationship between G_s and g_{ps} for which (2) has a longer lifetime than (1) to fifth order, and an argument will be given to show that this situation probably persists if higher order terms are included. Therefore, heavy neutral scalar mesons could be sufficiently stable against decay through virtual nucleon states into lighter bosons to be observed in cosmic ray experiments.

[1] A. Salam, Phys. Rev. **82**, 217 (1951).

Y6. Multiple Meson Production. H. W. LEWIS, *Institute for Advanced Study*.*—The analysis of the effect on the pseudoscalar field theory of multiple-meson production, of the correlations induced by the presumed softness of the inter-nucleon potential, has been carried out along the lines previously mentioned.[1] The results to be discussed include: (1) The mesonic multiplicity, which is reduced by a factor α, approximately equal to $(2\mu/M)^{\frac{1}{2}}$, where μ/M is the mass ratio of meson and nucleon.[2] The factor μ arises from the identification of the range of the force with the meson Compton wavelength —if this identification is not made, α can be varied somewhat. (2) The meson angular distribution, which is no longer spherically symmetric in the center of mass system, but involves cones of angular width $\sim\alpha^{\frac{1}{2}}$. (3) The implications for the theory of the observed symmetric double cone in the center of mass sytem.

* Now at the Bell Telephone Laboratories, Murray Hill, New Jersey.
[1] Proceedings of the Berkeley Statistical Symposium, University of California Press, 1952.
[2] Lewis, Oppenheimer, and Wouthuysen, Phys. Rev. **73**, 127 (1948).

Y7. Intrinsic Properties of the τ-Meson Derived from Conservation Laws.—B. A. JACOBSOHN, *University of Washington.*—Although meson-theoretic studies of the $\tau^+\rightarrow(3\pi)$ decay have been made, apparently no arguments have been published in which deductions are made solely on the basis of conservation of angular momentum and parity, as in Yang's[1] well-known treatment of two-photon decay. We make the following assumptions: (i) the (π^+, π^0) and (π^+, γ) processes are not observed because they are strictly forbidden, (ii) the π^+ is pseudoscalar and (iii) the π^0 has spin zero. Simple symmetry arguments then show that (i) is true only if the τ has spin zero and the same parity as the π^0. Similar arguments show that $\tau^+\rightarrow 2\pi^+ + \pi^-$ is forbidden if τ is scalar and allowed if τ is pseudoscalar. Thus, within the framework of our assumptions (which will be discussed), one can deduce that the τ^+ and π^0 are both pseudoscalar without appealing to meson theory.

[1] C. N. Yang, Phys. Rev. **77**, 242 (1950).

Y8. Scattering of Pi-Mesons by the Deuteron. J. S. BLAIR* AND B. SEGALL,† *University of Illinois.*—Exchange and ordinary scattering are considered in the impulse approximation[1] in which the single nucleon amplitudes are those given by the weak coupling theory. For a general type of nucleon-meson coupling, linear in the meson field, the conventional second-order perturbation theory is shown to yield a result that is approximately equal to this impulse approximation. As an illustrative example, numerical results are presented for the case of a pseudoscalar meson with pseudovector coupling. Differential cross sections for the single nucleon and elastic deuteron scattering are computed in a straight forward manner. The summation method of Chew and Placzek is used to obtain the approximate differential cross sections summed over all possible final states.

* Assisted by the joint program of the ONR and AEC.
† University of Illinois Post-Doctoral Fellow.
[1] G. F. Chew, Phys. Rev. **80**, 196 (1950).

Y9. Meson-Nucleon Scattering and Nucleon Isobars. KEITH A. BRUECKNER, *Indiana University.*—The scattering (including charge exchange) of π^- mesons in hydrogen rises from 18 millibarns[1] at 60 Mev to a broad plateau of about 60 millibarns[2] at 200 Mev, and is smaller than the π^+ scattering at 60 Mev in the ratio of 1.58 ± 0.24.[1] The general features of the π^- scattering, except for the high energy plateau, are given qualitatively by pseudoscalar theory with pseudovector coupling in the weak coupling limit; the ratio of π^+ to π^- scattering predicted by this theory is the weak coupling limit is, however, 0.60 which is much lower than the experimental result. A phenomenological theory of the scattering is developed using the methods of Wigner and Eisenbud[3] and imposing the restrictions of charge symmetry. Using the qualitative assignment of the resonance levels parameters as given by weak and strong coupling theory,[4] satisfactory agreement with experiment is obtained. It is concluded that the apparently anomalous features of the scattering can be interpreted to be an indication of a resonant meson-nucleon interaction corresponding to a nucleon isobar with spin $\frac{3}{2}$, isotopic spin $\frac{3}{2}$, and with an excitation of 277 Mev.

[1] Isaacs, Sachs, and Steinberger; post-deadline paper at the Chicago Physical Society meeting, October 27, 1951.
[2] Reported by H. L. Anderson at the Chicago Conference on High Energy Physics, September 15–19, 1951. Bull. Am. Phys. Soc. **26**, No. 6, 33 (1951).
[3] E. P. Wigner and L. Eisenbud, Phys. Rev. **72**, 29 (1947). H. Feshbach, D. C. Peaslee, and V. F. Weisskopf, Phys. Rev. **71**, 145 (1947).
[4] W. Pauli and S. M. Dancoff, Phys. Rev. **62**, 85 (1942).

Y10. The Pseudoscalar Interaction.* L. L. FOLDY, *Case Institute of Technology.*—The problem of a single nucleon (Dirac particle) moving in an external neutral pseudoscalar potential with pseudoscalar coupling is examined by the employment of unitary transformations. A first exact transformation eliminates the pseudoscalar coupling and yields a Hamiltonian describing a Dirac particle, whose rest mass varies with position, coupled to the potential by a nonlinear saturating pseudovector coupling. By a sequence of further transformations to eliminate odd operators, a new Hamiltonian suitable for the investigation of nonrelativistic problems is obtained as an expansion in powers of the ratio of nucleon Compton wavelength to the range of the potential, no assumption being made concerning the smallness of the potential itself. As a rough model of the deuteron, a form for the potential is assumed corresponding to the pseudoscalar meson potential produced by an infinitely heavy nucleon whose spin is also treated as a dynamical variable. It is found that no singlet or triplet bound states exist because of the strong repulsion arising from the dependence of rest mass on position. A strong spin-orbit coupling term is found to be present but of the opposite sign to that required by the Mayer shell model of the nucleus. Indications that the same results may obtain in the pseudoscalar meson theory with pseudoscalar coupling will be discussed.

* Supported by the AEC.

Y11. On the Non-Adiabatic Treatment of the Relativistic Two-Body Problem. MAURICE M. LÉVY, *Institute for Advanced Study.*—The method of Tamm and Dancoff,[1] for the non-adiabatic treatment of the relativistic interaction between two particles, has been generalized to include pair creation and higher order effects in the exchange of field quanta. This generalized form of the Tamm-Dancoff method gives results equivalent to those obtained from the relativistic equation of Bethe and Salpeter.[2] A detailed study has been made of two limiting cases: (a) the maximum number of mesons present at a given time is one, the number of pairs being unrestricted; (b) no pair of interacting particles is created, but an arbitrary number of mesons can be present. This method has been applied to the calculation of the lowest order correction to the scalar meson interaction of two nucleons. The exact correction, which is of the second order in nucleons velocities, is obtained by including the fourth- and sixth-order interaction processes involving, in the corresponding Feynman diagrams, the crossing of the meson lines. The numerical results of the application of this method to the weak coupling treatment of the relativistic pseudoscalar meson theory of the neutron-proton system will be reported.

[1] I. Tamm, J. Phys. U.S.S.R. **9**, 449 (1945); S. M. Dancoff, Phys. Rev. **78**, 382 (1950).
[2] H. A. Bethe and E. Salpeter, Phys. Rev. **82**, 309A (1951); M. Gell-Mann and F. Low, Phys. Rev. **84** (1951).

SATURDAY AFTERNOON AT 2:00

McMillin

(C. H. TOWNES presiding)

Invited Papers in Optical Physics

Z1. 1420-Mc Radiation from Interstellar Hydrogen. H. I. EWEN, *Harvard University.* (30 min.)

Z2. Pure Quadrupole Spectra of Solid Chlorine Compounds. RALPH LIVINGSTON, *Oak Ridge National Laboratory.* (30 min.)

Z3. Optical Hyperfine Structure by Techniques of Atomic Beams. G. K. WOODGATE, *Columbia University.* (30 min.)

SATURDAY AFTERNOON AT 2:00

Pupin 428

(C. F. SQUIRE presiding)

Cryogenics

ZA1. Lattice Oscillations and Superconductivity. M. DRESDEN, *University of Kansas.*—The theories which attempt to explain superconductivity on the basis of a strong interaction between the electrons and the oscillations of a crystal lattice have been criticized by Wentzel and others,[1] who demonstrated that under the conditions required for the existence of the superconductive state, the lattice oscillations would become unstable. Because of the conflicting interpretations of this result, the question of the interaction between lattice vibrations and an electron gas has been re-examined for the case of a linear chain. A part of the difficulty stems from the fact that the Hamiltonian used to describe the system cannot be separated in an unambiguous fashion in Hamiltonians referring to the electron-ion system, the lattice vibrations, and the interaction between these systems. In the customary description the frequencies of the normal modes may depend on the strength of the coupling. The treatment was carried out describing the lattice oscillations by the Born and v. Karman method, the electron gas was described using the Tomonaga representation of a non-ideal Fermi gas. Preliminary results indicate that the question of stability or instability depends sensitively on the method of separation and identification of the terms in the original Hamiltonian.

[1] G. Wentzel, Phys. Rev. **83**, 168 (1951).

ZA2. Further Considerations Regarding the Theory of Bose-Einstein Liquids.* J. G. DAUNT, T. S. TSENG, AND C. V. HEER, *Ohio State University.*—Previously Heer and Daunt[1] have shown that a quasi-gaseous model of a Bose-Einstein liquid can be used to explain the properties of dilute solutions of He^3 in liquid He^4. Further calculations, using the same model are reported, extending the results to strong solutions of He^3 in liquid He^4, and comparing them with recent experimental results.[2] It is found that the calculated values for the distribution coefficient are in agreement with experiment over a wide range of He^3 concentrations. At low temperatures (below 1.7°K) the numerical agreement is exact, and at the higher temperatures (above T_λ) the theoretical prediction of values well above those calculable for perfect classical solutions appears to be sustained by the experiments. Detailed calculations for vapor pressures of strong solutions are also given. Finally, a comparison is given with the theory of de Boer and Gorter,[3] for which detailed computations also have been made for strong solutions.

* Assisted by a contract between the AEC and The Ohio State University Research Foundation.
[1] C. V. Heer and J. G. Daunt, Phys. Rev. **81**, 447 (1951).
[2] See reference 1, abstract.
[3] J. de Boer and C. J. Gorter, Physica **16**, 225, 667 (1950).

ZA3. The Solubility of He^3 in Liquid He^4.* J. G. DAUNT AND C. V. HEER, *Ohio State University.*—Measurements are reported of the distribution coefficient for He^3 between solutions of He^3 in liquid He^4 and their saturated vapors in the temperature range 1.4°K to 2.6°K. The results obtained below the λ-temperature give values for C_v/C_L higher than those calculable for perfect classical solutions, but in good agreement with the theory previously proposed by Heer and Daunt.[1] Above 2.18°K, the λ-temperature for pure liquid He^4, the measured C_v/C_L also appears greater than that for perfect classical solutions, as was predicted by Heer and Daunt.[1] A comparison with the theory of de Boer and Gorter[2] is also given.

* Assisted by a contract between the AEC and the Ohio State University Research Foundation.
[1] C. V. Heer and J. G. Daunt, Phys. Rev. **81**, 447 (1951).
[2] J. de Boer and C. J. Gorter, Physica **16**, 225, 667 (1950).

ZA4. Low Temperature Heat Capacity of Niobium. A. BROWN, M. W. ZEMANSKY,* AND H. A. BOORSE,† *Columbia University.*‡—The heat capacity of niobium has been measured in the normal and superconducting states between 2.5° and 20°K. A special type carbon composition resistor was found to be a very satisfactory thermometer.[1] The data confirmed the usual relations, $C_n=\gamma T+464.4(T/\theta_n)^3$, and $C_s=464.4(T/\theta_s)^3$, where $\theta_n=254°$, and $\theta_s=161°$. The coefficient, γ, of the linear term in C_n was found to be 21.0×10^{-4} cal/mole-deg². The Debye characteristic temperature in the normal state, θ_n, is constant at 254° below 12°K, and then increases to approximately 268° at 20°K. In the superconducting state below 3.5°K the specific heat appeared to be significantly smaller than that given by the T^3 relation. The temperature at which $C_n=C_s$ was found to be $T_0/\sqrt{3}$, ($T_0=8.7$°K, the zero field transition temperature), thus indicating that the parabolic relation between the critical field, H, and the absolute temperature holds for niobium. The value of the critical field at absolute zero, H_0, was computed to be 1950 gauss. This value of H_0 is considerably smaller than any of the previous values determined by magnetic measurements.

* The City College of New York.
† Barnard College, Columbia University.
‡ Assisted in part by the ONR and Linde Air Products Company.
[1] Brown, Zemansky, and Boorse, Phys. Rev. **84**, 1050 (1951).

ZA5. The Specific Heat of Chromium below Room Temperature. J. WEERTMAN, D. BURK, AND J. E. GOLDMAN, *Carnegie Institute of Technology*.—Anomalous properties have been observed in chromium at 121°K.[1] The thermal properties of chromium at other temperatures also show a remarkable behavior. At high temperatures the specific heat is found to be anomalously high,[2] while at liquid helium temperatures the electronic specific heat determined from the linear term in the temperature dependence[3] is particularly low for a transition metal. The suggestion that these properties, and in particular the anomalies observed at 121°K, might be due to an antiferromagnetic transition prompted us to examine the specific heat of chromium at temperatures between liquid helium and room temperature. The experimental technique and thermometry is the same as that used by Estermann and his collaborators.[4] The sample is in the form of very pure electrolytically deposited flakes kindly supplied by the Allegheny-Ludlum Steel Corporation. The results show the usual Debye specific heat curve with no trace of any anomaly in the region of the Fine point. Values of the Debye θ agree well with published values at both extremes of the temperature range.

[1] Fine, Greiner, and Ellis, J. Metals **189**, 56 (1951).
[2] L. D. Armstrong and H. Grayson-Smith, Can. J. Research **28A**, 51 (1950).
[3] Friedberg, Estermann, and Goldman (to be published).
[4] I. Estermann and J. Weertman, Phys. Rev. **83**, 228 (1951).

ZA6. The Specific Heat of Hafnium at 40–190°K. D. BURK AND F. DARNELL, *Carnegie Institute of Technology* (Introduced by I. Estermann).—The anomalous peak in the specific heat of germanium which was found by Cristescu and Simon[1] to occur at 75°K was not found when this experiment was repeated in this laboratory.[2] Since these investigators found a similar peak in hafnium at the same temperature, it was suggested that the measurements on Hf be repeated. A sample of relatively pure metallic hafnium was made available for this purpose by the AEC. The calorimetric technique is similar to that employed by Estermann and Weertman. As in the earlier experiments, temperature measurements were made with a platinum resistance thermometer. The sample is in the form of a solid cylinder $\frac{5}{8}$ in. in diameter and 1 in. in length and consists of solid cast hafnium extremely pure except for approximately 2 percent zirconium. Measurements were carried out in the temperature range of 40°–190°K and give a monotonically increasing Debye curve over the entire range. The anomaly of Cristescu and Simon is completely absent.

* Supported by the ONR.
[1] S. Cristescu and F. Simon, Z. physik. Chem. **25B**, 273 (1934).
[2] I. Estermann and J. Weertman, Phys. Rev. **83**, 228 (1951). J. R. Weertman, thesis, Carnegie Institute of Technology, 1951.

ZA7. On the Superconductivity of a Hafnium-Zirconium alloy. L. D. ROBERTS AND J. W. T. DABBS, *Oak Ridge National Laboratory*.—The magnetic susceptibility of a hafnium-zirconium alloy has been observed between 0.22°K and 4.18°K and no evidence of superconductivity has been found in this temperature region, possibly contrary to the result of Kürti and Simon[1] who reported a transition at 0.35°K. Two hafnium samples, containing about 5 percent zirconium, were used, one prepared by chemical reduction and the other by the "hot wire" method. The latter "crystal bar" sample had a metal volume of 0.87 cc consisting of chips roughly 0.003 cc in volume pressed with 1.14 cc of $CrK(SO_4)_2\cdot 12H_2O$. Upon demagnetization of this composite to a final $H=0.44$ oersted, the final $T^*=0.22$°K (reciprocal susceptibility) was within 0.002°K of that expected for the pure alum, demonstrating the absence of a superconducting transition. Further, the susceptibility-time curve was linear during the warm up to 1.1°K (usually requiring about 40 minutes). In one experiment the sample was held below 0.25°K for 80 minutes to allow ample time for thermal equilibrium. A duplicate experiment on zirconium gave a very sharp transition at a temperature of 0.63°K. It is planned to extend the hafnium measurements to lower temperatures.

[1] Kürti and Simon, Proc. Roy. Soc. (London) **151**, 610 (1935).

ZA8. The Gyromagnetic Effect in a Superconductor. ROBERT PRY AND ARTHUR L. LATHROP, *Rice Institute*.—Experiments have been completed on measuring the gyromagnetic effect in superconducting tin with results in agreement with Kikoin and Gubar.[1] A tin sphere one inch in diameter was suspended from a torsion fiber and the delicate system driven at resonance by means of reversing a magnetic field (100 gauss and 50 gauss magnitudes). The change of magnetization gave an angular momentum change whose directional sense is that of a positively charged ion lattice under the influence of the Faraday induction of the oscillating magnetic field. The magnetization is caused by the orbital motion of the electrons.

[1] I. Kikoin and S. Gubar, J. Phys. U.S.S.R. **3**, 33 (1940).

ZA9. Spin Paramagnetism of Cr^{+++} at Liquid Helium Temperatures and High Magnetic Fields. WARREN E. HENRY, *Naval Research Laboratory*.—Experimental study of paramagnetism of suitable substances near saturation makes possible a critical examination of existing theories which embrace the ideas of quenching of orbital angular momentum[1] (Lande-g factor 2) and space-quantization[2] of magnetic dipoles. Magnetic moments of potassium chromium alum (containing Cr^{+++} of spin $\frac{3}{2}$) were measured in the liquid helium temperature range and in fields up to 50 kilogauss. For fixed values of magnetic field and temperature, a solid spherical sample of the alum was moved with respect to a double coil system, the resulting deflection of a ballistic galvanometer being proportional to the magnetic moment of the sample. Comparison with theory consisted of taking ratios between measured relative moments of the sample and the calculated magnetic moment for a given H/T. Constancy of these ratios is taken as agreement. The Brillouin space-quantized model[2] gives moments which agree with our experimental values ranging up to 99.5 percent saturation for the largest value of H/T.

[1] H. A. Jahn and E. Teller, Proc. Roy. Soc. (London) **A161**, 220 (1937).
[2] L. Brillouin, J. phys. et radium **8**, 74 (1927).

SATURDAY AFTERNOON AT 2:00

Schermerhorn 501

(L. J. HAWORTH presiding)

Reactions of Transmutation

ZB1. Excitation and Disintegration of Nuclei by Electrons.* J. A. THIE,† C. J. MULLIN, AND E. GUTH, *University of Notre Dame*.—The theory of the excitation and disintegration of nuclei by electrons has been extended and applied to a discussion of the feasibility and theoretical significance of some experiments which could be performed with electron beams.

General expressions have been developed for the cross sections for electron excitation of a nucleus because of the interaction of the electron's field with the electric 2^l-pole moments of the nucleus; unambiguous expressions are obtained for these cross sections because the form of the electric 2^l-pole moment does not depend upon the nuclear interactions.[1] The intimate relation between excitation by photons and by electrons has been developed explicitly. This relation has been exploited, in particular, in a comparison of the theory of the disintegration of the deuteron by high energy electrons with the corresponding photodisintegration theory. Because of the relative precision with which an electron beam can be controlled, electrons may be useful in high energy deuteron disintegration experiments.

* Supported in part by the ONR.
† AEC Predoctoral Fellow, now AEC Postdoctoral Fellow at Cornell University, Ithaca, New York.
[1] R. G. Sachs and N. Austern, Phys. Rev. **81**, 705 (1951).

ZB2. Photodisintegration of the Deuteron.* V. E. KROHN, JR., AND E. F. SHRADER, *Case Institute of Technology.*—The angular distribution of the protons from the $d(\gamma, n)p$ reaction has been investigated for 5–13-Mev gamma-rays by means of the D_2O loaded emulsion technique with the Case betatron serving as gamma-ray source. The results have been compared to a differential cross section of the form $d\sigma = \{a + (b+c\cos\theta)\sin^2\theta\}d\Omega$ in the center-of-mass system and the isotropy found consistent with the mean values: $a/b = 0.04 \pm 0.03$ from 5 to 11 Mev and 0.24 ± 0.07 from 11 to 13 Mev. The forward asymmetry was determined for energies above 8 Mev and found to be $c/b = 0.24 \pm 0.09$. Except for the isotropy observed above 11 Mev where the theory predicts $a/b \sim 0.01$ these results are in agreement with the theoretical calculations of Marshall and Guth[1] in which the possible effects of meson exchange currents and tensor forces are neglected.

* Work supported by the AEC.
[1] J. F. Marshall and E. Guth, Phys. Rev. **78**, 738 (1950).

ZB3. High Energy Photodisintegration of the Deuteron. T. S. BENEDICT AND W. M. WOODWARD, *Cornell University.**—The cross section for the photodisintegration of the deuteron has been measured in the energy range 80 to 150 Mev using 300-Mev synchrotron bremsstrahlung. The experimental arrangement, using a high pressure gas target and scintillation counters for detecting the protons, is essentially that used in a previous photodisintegration experiment[1] on He^4. The geometry of the present experiment has been improved by adding an internal collimator to the pressure chamber and decreasing the solid angles of the counting system. The chamber was filled with deuterium (>99.5 percent H^2) to a pressure of 120 atmospheres and protons were counted at laboratory angles of 60°, 90°, and 120°. The cross section at 80 Mev is in essential agreement with that calculated by Schiff[2] and Marshall and Guth,[3] while at higher energies it is somewhat greater than the theoretical prediction.

* Supported by the joint program of the ONR and AEC.
[1] T. S. Benedict and W. M. Woodward, Phys. Rev. **83**, 1269 (1951).
[2] L. I. Schiff, Phys. Rev. **78**, 733 (1950).
[3] J. F. Marshall and E. Guth, Phys. Rev. **78**, 738 (1950).

ZB4. Excitation Functions for Photoprotons from Carbon. A. M. PERRY AND J. C. KECK, *Cornell University.*—We have measured the yields of 60-, 100-, and 140-Mev protons from a carbon target bombarded by synchrotron γ-ray beams of maximum energy 310, 260, 215, and 180 Mev. The protons were detected by a two-crystal coincidence telescope,[1] at a mean angle of 67° with respect to the γ-rays. Proton energies were determined by copper absorbers in front of the telescope. The energy intervals were determined by discriminator bias on the output of the second crystal and by target thickness. Positive identification of the protons was by their pulse height in the first crystal. Cross sections per γ-ray for producing protons of a given energy were found to be roughly proportional to γ-ray energy above some threshold, which depends on the proton energy, and to decrease rather sharply below this threshold.

[1] J. C. Keck, Cornell thesis (1951); to be published in Phys. Rev.

ZB5. Gamma-Rays from Sodium Bombarded by Protons.* P. H. STELSON, W. M. PRESTON, AND CLARK GOODMAN, *M.I.T.*—The gamma-ray yield from sodium was measured as a function of proton bombarding energy over the range 1.0 to 2.6 Mev using resolutions of 1.5 to 10 kev. Thin targets of metallic sodium were prepared by evaporation in vacuum. Gamma-rays were detected with a NaI(Tl) scintillation counter. Thirty-seven resonances were found, giving an average level spacing of 40 kev at an average excitation energy of 13.5 Mev in the compound nucleus, Mg^{24}. The present results are in general agreement with the earlier work of Burling.[1] The resonances vary in natural width from less than 1.5 kev to 70 kev. The energy spectrum of the gamma-rays from a number of the resonances was investigated with a single crystal NaI(Tl) scintillation spectrometer. Only the very sharp resonance at $E_p = 1.415$ Mev gave appreciable proton capture radiation. The spectra of the other resonances consist mainly of two gamma-rays with energies of 0.45 ± 0.01 and 1.63 ± 0.02 Mev. These are interpreted as resulting from transitions from the first excited states of the residual nuclei formed by the reactions: $Na^{23}(p, p')^*Na^{23}$ and $Na^{23}(p, \alpha)^*Ne^{20}$, respectively.

* Work jointly supported by ONR and BuShips.
[1] R. L. Burling, Phys. Rev. **60**, 340 (1941).

ZB6. Angular Distributions of Photoprotons.* M. A. ROTHMAN, A. K. MANN, AND J. HALPERN, *University of Pennsylvania.*—Targets of Co, Ni, and Cu have been bombarded with bremsstrahlung of maximum energy 23 Mev. The angular distributions of all the emitted protons from each target have been measured with ZnS scintillation counters.[1] Preliminary data indicate that within the precision of the measurements, approximately ±5 percent, protons are emitted isotropically from Ni. The distribution from Cu appears to be peaked in the forward direction with a ratio of 1.17 between the number of protons observed at 45 and at 150 degrees. The distribution from Co is similar to that from Cu. Departures from the assumptions of the statistical theory which might account for the observed angular distributions will be discussed.

* Supported in part by a contract with the Air Force.
[1] A. K. Mann and J. Halpern, Phys. Rev. **82**, 733 (1951).

ZB7. (p, n) Yields from the Light Elements. HARVEY B. WILLARD AND JOE KEAGY BAIR, *Oak Ridge National Laboratory.*—The yields of neutrons from the proton bombardment of T, Li^7, Be^9, B^{11}, and F^{19} have been extended with 0.1 percent resolution to 5.3 Mev. The neutrons produced in the forward direction were measured with a conventional "long" counter and monitored by a beam current integrator. T exhibits a gradual increase up to 4.22 Mev, where it rises more rapidly as though approaching a very broad resonance. New maxima were observed in the yield from Li^7 at 4.90 Mev (broad), from Be^9 at 4.72 Mev (broad), and from B^{11} at 3.17, 3.75, 4.14, and 4.67 Mev (all broad). The $F^{19}(p, n)Ne^{19}$ threshold was determined to be 4.253 ± 0.005 Mev and narrow maxima occur at 4.29, 4.46, 4.49, 4.57, 4.62, 4.71, 4.78, 4.99, 5.07, and 5.20 Mev.

ZB8. Disintegration of Helium by 90-Mev Neutrons. P. TANNENWALD, *University of California, Berkeley.*—90-Mev neutrons produced by stripping 190-Mev deuterons in the 184-inch cyclotron were collimated and sent through a 22-inch Wilson cloud chamber filled with helium gas to a total pressure of 81 cm Hg. The chamber was operated in a pulsed magnetic field of 21,700 gauss. The possible reaction products are: triton-deuteron, 2 deuterons-neutron, triton-proton-neutron, deuteron-proton-2 neutrons, 2 protons-3 neutrons, He^3-2 neutrons, He^4 recoils. The particles from the two-prong stars are identified by curvature and relative ionization, and the single tracks by characteristic track endings when they end in the chamber. For the first three reactions it is possible to calculate, from measured quantities, the energy of the incident neutron. Of the 90 two-prong stars which have been analyzed so far, there are 18 *dt*, 10 *dd*, 47 *pt*, 14 *pd*, 1 *pp*. 59 He^4 tracks ended in the chamber, and 78 other single tracks were observed which did not end. All these events occurred within an angle of $\pm 30°$ to the horizontal plane containing the neutron beam. Relative cross sections and energy and angular distributions will be presented.

ZB9. The Disintegration of He^3 by Deuterons.* A. B. LILLIE, T. W. BONNER, AND J. P. CONNER, *Rice Institute*.—The reaction $He^3(d, p)He^4$ has been studied, when deuterons of energy 200–1600 kev have bombarded a gaseous thin target of He^3. The absolute number of high energy protons which are produced were observed in the direction of the incident deuterons. The curve of the differential cross section for the reaction at 0° shows a peak at 400-kev deuteron energy and a half-width of 500 kev. The differential cross section is 50 millibarns per unit solid angle at 400 kev and drops to 10 millibarns per unit solid angle at 1600 kev. The results indicate an excited level in Li^5 at 18.5 Mev above the ground state.

* Assisted by the AEC.

ZB10. Angular Distribution of α-Particles from $Li^7(t, \alpha)He^6$. T. P. PEPPER, E. ALMQVIST, AND P. LORRAIN,* *Chalk River Laboratories*.—The angular distribution of the α-particle groups from the reactions[1] $Li^7(t, \alpha)He^6$ and $Li^7(t, \alpha)He^{6*}$ are being studied using two end-window proportional counters filled with A and CO_2. One counter, mounted at 90° to the 240-kev mass-3 beam, monitors the yield of α-particles from the target. The second counter can be set to detect α-particles emitted at chosen angles to the beam. By displaying the pulses from this counter on a 30-channel pulse-height analyzer the yields of the two α-particle groups are observed simultaneously at each angle. Measurements have been made from 75° to 135° to the beam in the center-of-mass system. The angular distribution of the α-group associated with the ground state of He^6 is of the form $1-A\cos^2\theta$ with $A\sim 1$, while that of the α-group associated with the excited state of He^6 is nearly isotropic.

* Permanent address: University of Montreal, Montreal, Quebec.
1 Pepper, Allen, Almqvist, and Dewan, Phys. Rev. 81, 315(A) (1951).

ZB11. Reactions of 370-Mev Protons with Cobalt.* E. BELMONT† AND J. M. MILLER, *Columbia University*.—Cross sections have been evaluated for the formation of various products resulting from the irradiation of cobalt with 370-Mev protons in the circulating beam of the Columbia University Nevis cyclotron. The elements from scandium to cobalt are formed in greatest yield; total cross sections of the order of 50–80 millibarns have been found for each of these elements by interpolating values for stable isotopes. On the other hand, nuclei such as carbon and sodium are formed with cross sections of the order of 0.05 millibarn. These results are in accord with the hypothesis of nucleon-nucleon interactions leading to the loss of nucleons from the target by "knock-ons" followed by evaporation of particles from a spectrum of residual nuclei with a spectrum of excitation energy. The cross sections for the more probable events are in qualitative agreement with recent measurements on proton induced stars[1] and with Monte Carlo[2] and evaporation theory[3] calculations.

* Work performed under the auspices of the AEC.
† AEC Predoctoral Fellow.
1 L. Germain, Phys. Rev. 82, 596 (1951).
2 Bernardini, Booth, and Lindenbaum, Phys. Rev. 83, 669 (1951).
3 K. Le Couteur, Proc. Phys. Soc. (London) A63, 259 (1950).

ZB12. Gamma-Ray Resonances in the Proton Bombardment of Mg^{26}.* WARREN E. TAYLOR, L. N. RUSSELL, JOHN N. COOPER, AND J. C. HARRIS, *Ohio State University*.—Thin targets of Mg^{26} of relatively high purity[1] were formed on a tantalum backing by decomposition of heated MgO in a vacuum. An electrostatic generator provided protons in the energy range between 300 and 1200 kev. Presumably there was induced the reaction $Mg^{26}(p, \gamma)Al^{27}$, which has a calculated Q of approximately 7.5 Mev. The relative yield of gamma-rays per proton indicates well-resolved maxima for incident proton energies of 339, 449, 660, 726, 812, 843, 952, 986, 1011, 1053, and 1183 kev. These values are uncorrected for target thickness, estimated to be 15 kev at one Mev. The error is probably less than 10 kev throughout the range covered. The first two values agree well with two resonances previously reported by Tangen[2] at 336 and 451 kev. There is some evidence for other levels of low intensity in this same region.

* Assisted by a contract between the AEC and the Ohio State University Research Foundation.
1 Supplied by the Carbide and Carbon Chemical Division, Oak Ridge National Laboratory.
2 R. Tangen, Kgl Nord. Vid. Selsk. Skr. NR 1 (1946).

ZB13. Excited States of P^{32} from the $P^{31}(d, p)P^{32}$ Reaction.* D. M. VAN PATTER, P. M. ENDT,† A. SPERDUTO, AND W. W. BUECHNER, *M.I.T.*—The $P^{31}(d, p)P^{32}$ reaction has been investigated by means of magnetic analysis of the protons emitted from thin targets containing phosphorus bombarded by 1.8- and 2.0-Mev deuterons. Sixteen of the proton groups observed have been assigned to the $P^{31}(d, p)P^{32}$ reaction, corresponding to the ground state and fifteen excited states of P^{32}, in a region of excitation from zero to 4.3 Mev. The position of the first excited state of P^{32} has been measured as 77.0 ± 1.7 kev. Three other pairs of closely spaced levels were observed. These occurred at 2.2-, 2.7-, and 3.3-Mev excitation with spacings of 50 ± 2, 92 ± 7, and 59 ± 3 kev, respectively. Because of the presence of contaminant groups, it is possible that some $P^{31}(d, p)P^{32}$ groups were missed, corresponding to states in a region of excitation from 3.3 to 4.3 Mev. The nucleus P^{32} appears to have a large number of low-lying states, with the first level very near to the ground state.

* This work has been assisted by the joint program of the ONR and AEC.
† Now at the University of Utrecht, The Netherlands.

ZB14. Neutrons from the Disintegration of Phosphorus by Deuterons.* S. C. SNOWDON, *Bartol Research Foundation*.—The neutron spectrum at 0° and at 90° from the $P^{31}(d, n)S^{32}$ reaction has been investigated using nuclear emulsions. A ground-state Q value of 6.3 ± 0.2 Mev has been found and is in rough agreement with the latest evaluation of the masses of the nuclei involved. The Q values corresponding to the excited states in S^{32} are 5.7, 5.05, 4.2, 3.7, 3.15, 2.5, 1.7, 1.1, 0.5, and 0.05 Mev, each with an uncertainty of about 0.2 Mev.

* Assisted by the joint program of the ONR and AEC.

ZB15. Excited States of Mg^{25} from the $Al^{27}(d, \alpha)Mg^{25}$ and $Mg^{24}(d, p)Mg^{25}$ Reactions.* P. M. ENDT,† H. A. ENGE,‡ J. HAFFNER, AND W. W. BUECHNER, *M.I.T.*—The alpha-particle groups from thin aluminum targets bombarded with 1.8-, 2.0-, and 2.1-Mev deuterons have been studied with the M.I.T. high resolution magnetic spectrograph. Eleven of these groups have been assigned to the $Al^{27}(d, \alpha)Mg^{25}$ reaction, corresponding to the ground state and ten excited states of Mg^{25} in a region of excitation from zero to 4.0 Mev. The proton groups from a thin natural magnesium target were also studied at deuteron bombarding energies of 1.5, 1.8, and 2.0 Mev. Eleven of the observed proton groups could be assigned to the $Mg^{24}(d, p)Mg^{25}$ reaction, corresponding to the transition to the ground state of Mg^{25} and the same ten excited levels found from the $Al^{27}(d, \alpha)Mg^{25}$ reaction. The excited states in Mg^{25}

found from these two reactions are at 0.583, 0.976, 1.611, 1.957, 2.562, 2.736, 2.799, 3.405, 3.898, and 3.969 Mev.

* This work has been assisted by the joint program of the ONR and AEC.
† Now at the University of Utrecht, The Netherlands.
‡ On leave from the University of Bergen, Norway.

ZB16. Energy Levels in Mn^{53} from Scintillation Studies of $Cr^{53}(p, n, \gamma)Mn^{53}$.* Clyde L. McClelland, Clark Goodman, and Paul H. Stelson, *M.I.T.*—A single crystal NaI(Tl) scintillation spectrometer was used to determine the gamma-spectrum from $Cr^{53}(p, n, \gamma)Mn^{53}$ at several proton energies, $E_p > 1.406$ Mev, the reaction threshold.[1] The instrument was calibrated with the gammas from Cs^{137} (0.669 Mev) and Na^{22} (1.277 and 0.511 Mev). A target of chromium,[2] enriched to 90.06 percent Cr^{53} and approximately 25 kev thick was bombarded with protons from the Rockefeller electrostatic generator. The energies of the gammas observed are:

E_p (Mev)	Gamma-Energy (Mev ±2 percent)
1.75	none
2.00	0.385
2.40	0.385
2.90	0.385, 0.88, 1.27

These gammas are interpreted as resulting from two excited levels in the residual Mn^{53} nucleus, located at 0.385 and 1.27 Mev. Experiments are in progress to determine the relative intensities. Formation of twenty-five minute I^{128} in the crystal from neutron capture is observed at the higher proton energies. This technique supplements the laborious measurements of recoil protons in emulsions to determine the neutron groups.

* Work jointly supported by ORN and BuShips.
[1] Lovington, McCue, and Preston (to be published).
[2] Oak Ridge analysis of enriched Cr^{53}: 90.06 percent Cr^{53}, 0.465 percent Cr^{54}, 0.193 percent Cr^{50}, 9.28 percent Cr^{52}.

Saturday Afternoon at 2:00

Havemeyer 309

(M. Goldhaber presiding)

Radioactive Nuclei

ZC1. *K*-Capture and Positron Emission in ^{65}Zn. J. K. Major, *Institut du Radium and Collège de France, Paris.*—The radiations from 250-day ^{65}Zn have been studied with a variable-pressure cloud chamber,[1] and Geiger-Müller counters in coincidence, calibrated using standards of RaD+E+F and ^{55}Fe, and $\beta\gamma$-coincidences with ^{22}Na, ^{24}Na, ^{60}Co, and ^{198}Au. Absorption between source and counters was minimized by evacuating to 10^{-2} mm Hg, and the β, X, and γ-ray components evaluated using a magnetic field and critical absorption in iron foils. $X\gamma$ coincidences show that 55.2±2.1 percent of the K-captures go to the ground state, and absolute counting gives 2.5±0.1 percent for the fraction of all disintegrations by β^+ emission, confirming earlier results.[2] Contrary to other findings,[3] no $\beta\gamma$-coincidences were observed; if the β spectrum is simple, β^+ emission to an excited state is excluded by the energy available for the transition. The branching ratio of K-capture to positron emission (to the ground state only) was 25±10 from cloud-chamber observations and 21.3±1.4 from counting, consistent with other values. Agreement with the Fermi theory is best for a second-forbidden transition ($\Delta J=1$, $\Delta L=2$), confirmed by the ft value, but interpretation in terms of the shell model leads to certain difficulties.

[1] F. Joliot, J. phys. et radium (VII) 5, 216–218 (1934).
[2] W. M. Good and W. C. Peacock, Phys. Rev. 69, 680 (A) (1946); L. R. Zumwalt, Plut. Proj. Rec. Mon-N-432, 54 (1947).
[3] Watase, Itoh, and Takeda, Proc. Phys.-Math. Soc. Japan 22, 90–105 (1940); R. A. Cohn and J. D. Kurbatov, Phys. Rev. 78, 318 (A) (1950).

ZC2. Radioisotopes of Bromine. S. C. Fultz and M. L. Pool, *Ohio State University.*—Natural Se and Se enriched with Se^{76} were bombarded with 7.3-Mev protons and 10-Mev deuterons. The radiations of Br^{83}, Br^{80}, Br^{77}, Br^{76}, and Br^{75} have been examined by use of a 180° focusing spectrometer and coincidence methods. Br^{83} emits a simple negatron spectrum with a maximum energy of 0.94±0.02 Mev. The ground state of Br^{80} emits a complex negatron spectrum having components: 1.97±0.03 Mev (82 percent), 0.86 Mev (10 percent), 0.56 Mev (8 percent). The gamma-rays of Br^{77} are associated with the K-capture process. The 17.2-hour activity recently found in bromine and assigned to Br^{76} emits, from its ground state, positrons having a complex spectrum with components 3.57±0.07 Mev (46 percent), 1.66 Mev (10 percent), 1.13 Mev (11 percent), 0.80 Mev (14 percent), 0.63 Mev (19 percent). Gamma-rays identified with Br^{76} have energies of 0.25, 0.33, 0.37, 0.42, 0.68, 0.75, 0.96, and 1.2 Mev. The ground state of Br^{75} decays by emission of positrons having a complex spectrum with components: 1.70±0.02 Mev (46 percent), 0.80 Mev (20 percent), 0.58 Mev (15 percent), 0.33 Mev (19 percent).

ZC3. Characteristic Radiations of Zr^{97} and Nb^{97}.* C. E. Mandeville, E. Shapiro, R. I. Mendenhall, E. R. Zucker,† and G. L. Conklin, *Bartol Research Foundation.*—$Zr^{96}O_2$ (isotopic concentration 90 percent) was irradiated by slow neutrons in the Oak Ridge pile. The half-period of the niobium daughter element, chemically separated from zirconium, was found to be 72.1±0.7 minutes and that of Zr^{97} to be 17.0±0.2 hours. By aluminum absorption and Feather analysis, maximum beta-ray energies of 2.50 Mev and 1.40 Mev were measured for parent and daughter element, respectively. Lead adsorption of the quantum radiations of the equilibrium mixture indicated a gamma-ray at 0.74 Mev as well as a softer component. Coincidence absorption yielded a maximum gamma-ray energy of 1.42 Mev. The beta-gamma coincidence rate of Nb^{97} was constant, independent of the beta-ray energy and of such magnitude as to suggest that each beta-ray is followed on the average by 0.7 Mev of gamma-ray energy. The beta-gamma coincidence rate of the equilibrium mixture showed that the hard beta-rays of Zr^{97} proceed directly to the metastable state of Nb^{97}. Very few beta-rays of Zr^{97} are coincident with any gamma-radiation. A disintegration scheme will be proposed.

* Assisted by the joint program of the ONR and AEC.
† Frankford Arsenal.

ZC4. The Beta-Spectrum of Tc^{99}. Frank Wagner, Jr., and Melvin S. Freedman, *Argonne National Laboratory.*—A thin (95 μg/cm²) uniform sample, prepared by volatilization of NH_4TcO_4 in vacuum onto a 150 μg/cm² aluminum support, was examined in a double lens spectrometer at 4 percent resolution. The Kurie plot, corrected by C_{2T}[1] with $|A_{ij}|^2/|T_{ij}|^2=6.60$ and with $|\int\alpha\cdot r|^2=0$ is quite straight from $E_0=296$ kev down to 60 kev, and definitely does not fit the α-shape.[2] The contribution of backscattering from the aluminum foil was assayed by a comparison of the spectrum of Pm^{147}, also prepared by a vacuum volatilization technique using the trifluoro-acetyl acetonate, onto a 10 $\mu g/cm^2$ LC-600 film, with an added aluminum foil backscatterer. Without backscatterer present the Pm spectrum is linear from $E_0=227$ kev to 10 kev; with backscatterer, to 60 kev, deviating upwards by 6 percent at 30 kev. Application of the ratio as a correction to Tc^{99} extends the straight line to $\sim$35 kev. These results are in agreement with the shell model[3] assignment for this transition, $g_{9/2}-d_{5/2}$, and furnish, together with the high energy transition in Cs^{137},[4] a second confirmation for a predominantly tensor interaction on the basis of spectral shape.

1 Nakamura, Umezawa, and Takebe, Phys. Rev. **83**, 1273 (1951).
2 S. I. Taimuty, Phys. Rev. **81**, 461 (1951); Wu and Feldman, Phys. Rev. **82**, 332 (1951).
3 Mayer, Moszkowski, and Nordheim, ANL-4626 (May, 1951).
4 Langer and Moffat, Phys. Rev. **82**, 635 (1951); also confirmed by the authors (to be published).

ZC5. The Angular Correlation of the Pd^{106} Gamma-Rays.* ROLF M. STEFFEN, *Purdue University*.—A possible explanation of the observed angular correlation of the Pd^{106} gamma-rays is the reduction of the correlation because of the magnetic field of the atomic shell. The ground state of the Pd^{106} atom however is a $^1S_0$-state, hence the atom must be highly excited or ionized in order to disturb appreciably the orientation of the nucleus during the rather short lifetime ($\sim10^{-11}$ sec) of the intermediate state. By embedding the decaying atoms in metals and in ionic crystals, it should be possible to change the correlation reducing effects in Pd^{106}.[1] Rh^{106} "metal sources" were prepared by electroplating the parent Ru^{106} with and without excess of Ag. In both cases the angular correlation was found to be the same within 2 percent as the one measured with a $RuCl_3$ source, whereas In^{111} sources prepared in exactly the same way exhibited both a maximum anisotropy of (18 ± 2) percent as compared to (7 ± 2) percent measured with $InCl_3$ sources. Sources in which the Rh^{106} formed a lattice defect in ionic crystals (AgCl, NaCl) showed no change in angular correlation, whereas with In^{111} sources prepared in a similar way a maximum anisotropy of (2 ± 2) percent was found. The results obtained with the In^{111} sources confirm the correlation measurements reported by Frauenfelder *et al.*[1]

* Work supported by the AEC.
1 Frauenfelder *et al.*, Phys. Rev. **82**, 549 and 550 (1951).

ZC6. Excitation of Metastable Cd^{111} by Inelastic Scattering of Neutrons.* J. J. G. McCUE, A. E. FRANCIS, AND CLARK GOODMAN, *Massachusetts Institute of Technology*.—We have studied the formation of metastable Cd^{111}, with 49-minute half-life,[1] by inelastic scattering of nearly monoergic neutrons. The plot of cross section *vs* neutron energy is concave toward the energy axis. The threshold is at 400 ± 20 kev; at 720 ± 20 kev, and 1150 ± 20 kev, there are cusps indicating excitation of higher levels. The threshold agrees with the excitation energy of the metastable state, known from conversion-electron spectra to be 396 kev.[2] The level at 1150 is perhaps the one reported at 1250 kev by Wiedenbeck[1] on the basis of electron bombardment; the 720-kev level is new. At 1350 kev, the cross section is 13.0 times as large as it is at 580 kev, where it has a local maximum. A preliminary measurement shows that the cross section at 1350 kev is roughly 0.4 barns, with a probable error estimated as a factor 2. A more precise measurement of the absolute cross section is in progress.

* Work jointly supported by the ONR and BuShips.
1 M. L. Wiedenbeck, Phys. Rev. **67**, 92 (1945).
2 Helmholz, Hayward, and McGinnis, Phys. Rev. **75**, 1469 (1949).

ZC7. The Spins of the Excited States of Cd^{114}.* M. W. JOHNS, C. D. COX, AND C. C. McMULLEN, *McMaster University*.—The gamma-gamma angular correlation function for the 552- and 722-kev gamma-rays of In^{114} has been determined using anthracene crystals with a coincidence circuit of resolution 5×10^{-9} sec.[1] The data are well represented by the equation $W(\theta)/W(\pi/2)=1-0.005\cos^2\theta+0.197\cos^4\theta$. This function, which is quite similar to the 0-2-4 correlation[2] can be uniquely described in terms of a 0-2-2 cascade in which the 2-2 transition is a mixture of M.D. (86 percent) and E.Q. (14 percent) radiation together with a 66° phase shift. By studying the photoelectrons ejected from a lead radiator, the relative intensity of the 1.27-Mev crossover transition has been measured as 3 percent of the cascade gammas. This intensity is consistent with the 0-2-2 but not with the 0-2-4 spin assignment. From the number of coincidences at the 180° position, it is possible to set an upper limit to the number of positrons at 5×10^{-6} per β^- disintegration.[3]

* Assisted by the National Research Council of Canada.
1 Petch and Johns, Phys. Rev. **80**, 478 (1950).
2 Steffen, Phys. Rev. **83**, 166 (1951).
3 Boehm and Preiswerk, Helv. Phys. Acta, **22**, No. 3, 331 (1949).

ZC8. The Decay of the Metastable State in In^{115}.* L. M. LANGER, R. D. MOFFAT AND G. A. GRAVES, *Indiana University*.—Using the large high resolution magnetic spectrometer, a precise measurement was made on the internal conversion electrons in the transition from the 4.5 hour metastable state of In^{115}. For this purpose, the activity was grown and extracted from the 54.0 hour Cd^{115} parent, which had been produced by deuteron bombardment in the cyclotron. The energy of the transition is 333.7 kev. The $K/L+M$ conversion ratio was found to be 3.76. This value is somewhat less than one might expect from the empirical curve[1] for a $M4$ transition. From spectrometer measurements made with a source in secular equilibrium with the 54-hour Cd^{115}, prepared by neutron capture† in enriched (94.2 percent) Cd^{114}, the total internal conversion coefficient is found to be 0.98 and the K conversion coefficient is 0.64. The 0.84-Mev beta-branch to Sn^{115} accounts for 5.5 percent of the transitions. The 54.0-hour Cd^{115} feeds the metastable level of In^{115} via two beta-groups with end points of 1.11 Mev (58 percent) and 0.58 Mev (42 percent).

* Assisted by a grant from the Frederick Gardner Cottrell Fund of the Research Corporation and by the joint program of the ONR and AEC.
1 M. Goldhaber and A. W. Sunyar, Phys. Rev. **83**, 906 (1951).
† In the Los Alamos nuclear reactor.

ZC9. The Beta-Spectrum of 2.3-Year CS^{134}. F. H. SCHMIDT AND G. L. KEISTER, *University of Washington*.—The electron radiations resulting from the decay of Cs^{134} have been studied in a high resolution solenoidal spectrometer. Conversion electrons have been observed from seven gamma-rays; *viz.*, 561.5 ± 1.0, 566.5 ± 0.8, 601.2 ± 0.5, 793.1 ± 0.7, 1037.2 ± 2.6, 1164.4 ± 2.9, and 1365.7 ± 3.3 kev. The two lowest energy gammas, whose ratio of K electron intensities is $\sim$0.5, correspond to the single gamma-ray found by other workers.[1] The three high energy lines are very weak; the measured K-L differences do not exclude conversion in Xe, but indicate that conversion is more probably occurring in Ba. There is no evidence of a contaminant. The continuous spectrum shows some indication of two high energy components whose end points differ by 30–40 Kev. The end point of the low energy branch ($\sim$24 percent) is $\sim$79 kev. On the basis of these energies and other data,[2] a fairly consistent scheme for Ba^{134} can be constructed with levels at 793, 1359, 1394, and 1955 kev. The K internal conversion coefficients for the 793 and 601 gammas can be found with reasonable certainty; *viz.*, 2.1 ± 0.2 and $5.7\pm0.5\times10^{-3}$, respectively. Coefficients for the 561 and 566 depend strongly upon which is associated with the low energy beta-branch. The role of the 1037 gamma is very uncertain. Partial support of the AEC is acknowledged.

1 Waggoner, Moon, and Roberts, Phys. Rev. **80**, 420 (1950).
2 Elliot and Bell, Phys. Rev. **72**, 979 (1947).

ZC10. Beta-Spectra of Ce^{144} and Pr^{144}. CHENG, LIN-SHENG, G. JOHN, AND J. D. KURBATOV, *Ohio State University*.—Ce^{144},

$T_{\frac{1}{2}}$~275 day, carrier free fission product, was aged and purified partly without addition of carrier and partly with addition of carrier. The beta-spectra of these two samples were studied with a solenoidal spectrometer. Three beta-spectra were identified in Pr^{144} and two beta-spectra in Ce^{144}. The beta spectra of Pr^{144} are with upper energy limits 3.00±0.06 Mev, 1.30±0.02 Mev and 605±8 kev. Their relative intensities have been estimated to be 85±5 percent, 12±2 percent, 3±1 percent. The beta-spectra of Ce^{144} have upper energy limits 446±8 kev, 307±6 kev and relative intensities 3±1 percent, 97±1 percent. The partial half-lives calculated from the relative intensities are compatible with the *ft* values estimated from degree of forbiddenness, except in the case of the 605-kev beta-spectrum. The conversion lines of low energy gamma-rays were observed. They were identified as the *L*-line of 54.7±0.5 kev, *K* and *L* lines of 79.4±0.8 kev, 134±1 kev, and 231±2 kev gamma-rays. The *K/L* ratios of the latter three were estimated to be 6.3±0.7, 8.3±0.6, 1.7±0.3, respectively.

ZC11. The Decay Scheme and Angular Correlation of Pr^{144}.* D. E. ALBURGER AND J. KRAUSHAAR, *Brookhaven National Laboratory*.—Beta-rays of maximum energy 2.965±0.015 Mev (90 percent), 2.3±0.1 Mev (~5 percent), and 0.86±0.1 Mev (~5 percent) have been found in the decay of 17-min Pr^{144} with a lens spectrometer. Gamma-rays of 0.695±0.005 Mev, 1.48±0.01 Mev, and a cross-over of 2.185±0.015 Mev with relative intensities of 1:0.4:1.1, respectively, are associated with this activity. Coincidences between gamma-rays are present and exhibit an angular correlation of the form $1-0.33\cos^2\theta$ characteristic of either a 1-1-0 or a 1-2-0 cascade. A decay scheme is proposed in which the first excited state of Nd^{144} is at 0.695 Mev and has spin 2 and even parity. The second level at 2.185 Mev has spin 1 and even parity. All beta-transitions are allowed by selection rules if Pr^{144} is assigned spin 1 and even parity. The 300-kev beta-spectrum and internal conversion lines of a 135-kev gamma-ray in the decay of the mother 282-day Ce^{144} have been observed. This high yield fission-product isotope is suggested as a useful reasonably long-lived source of homogeneous photo-neutrons from Be in which the gamma-ray occurs in about 3 percent of beta-decays.[1] The authors are indebted to S. Katcoff for chemical purification of the beta-source.

* Research carried out under contract with the AEC.

[1] Alburger, der Mateosian, Goldhaber, and Katcoff, Phys. Rev. **82**, 332(A) (1951).

ZC12. Europium 148 and 150. REX C. MACK, DONALD I. PRICKETT, AND M. L. POOL, *Ohio State University*.—Bombardments of the enriched isotopes of Sm^{148}, Sm^{149}, and Sm^{150} have given rise to two new and well-defined activities, one with half-life of 13.1-hours, and one with half-life of 58.6-days. The 13.1-hour activity was shown to be a negative beta-activity with complex spectrum, the main component of the spectrum having an end point of approximately 0.85 Mev. This activity is assigned to Eu^{150} and the assignment leads to the prediction that Gd^{150} has a half-life of 10^4 years or longer. The 58.6-day activity, which consisted primarily of electromagnetic radiation, decayed by *K*-electron capture. This activity is assigned to Eu^{148}. Gamma-rays of 0.69 Mev and internal conversion electrons were observed in connection with the activity.

ZC13. Experimental Determination of *K/L* Ratios for $_{71}Lu^{175}$ and $_{21}Sc^{46m}$ (20 Seconds). S. B. BURSON AND W. C. RUTLEDGE, *Argonne National Laboratory*.—Neutron activation of $_{72}Hf^{174}$ produces 70-day $_{72}Hf^{175}$, which decays by *K*-capture to $_{71}Lu^{175}$. In addition to the four γ-rays of 0.089, 0.113, 0.228, and 0.342 Mev reported,[1] two more of 0.318 and 0.431 Mev are found to be associated with $_{71}Lu^{175}$. These are shown to be consistent with the proposed energy level scheme. By use of both the 180° β-ray spectrometer and the photographic spectrograph, *K/L* ratios were measured for most of the lines. The type of radiation is suggested for each γ-ray, and spin and parity changes are assigned. To compare the two methods of measurement, the highly converted 0.342 Mev γ-ray was used. A *K/L* ratio of 4.95±0.25 was determined from area measurements of photodensitometer traces of the plates and found to be in good agreement with a value of 4.93±0.20 determined from the spectrometer momentum plot. Thus, the photographic method, when properly calibrated, provides a reliable means of *K/L* ratio determination for activities too short-lived to be measured by other methods. The isomeric transition in $_{21}Sc^{46m}$ (20 seconds) was measured as 0.142 Mev. A *K/L* ratio of 10±3 is determined from the plate.

[1] Burson, Blair, Keller, and Wexler, Phys. Rev. **83**, 62 (1951).

ZC14. Radiations of Th^{231}(UY). M. S. FREEDMAN, F. WAGNER, JR., A. H. JAFFEY, AND J. MAY, *Argonne National Laboratory*.—The electron spectrum of Th^{231}(UY) was examined on our double lens spectrometer with a resolution of 3 percent. The samples were separated carrier-free from isotopically pure U^{235} by solvent extraction. Sample thickness in order of 50 μg/cm² mounted on about 10 μg/cm² film was employed. We find three β-components with maximum energies 302 kev (44 percent), 216 kev (11 percent), and 93 kev (45 percent) and 19 conversion lines assignable to gammas of 208, 167, 107, 85, 63, 59, and 22 kev. Each of these gammas was directly observed on a scintillation spectrometer using thalliated sodium iodide. The less intense gammas were emphasized experimentally with respect to the strong 59-, 63-, and 85-kev gammas by the use of absorbers. An additional gamma of 122 kev was observed only in the scintillation spectrometer. A decay scheme will be presented.

SUPPLEMENTARY PROGRAMME

SP1. Theory as Organization of Observation. JEROME ROTHSTEIN, *Signal Corps Engineering Laboratories.**—Define organization for elements individually associated with characteristic sets of alternatives as the excess in entropy of the ensemble of distinguishable alternatives of the composite system computed for independent elements over the entropy of the set of alternatives when the correlations (constraints, interactions, controls, instructions) characterizing the organized system are operative. Define organizational redundancy as the excess of maximal organization consistent with the alternatives required of the system over actual organization present. Organization is then information (as in communication) or negative entropy (as in physics), and provides a rational basis for system engineering design. Measurement yields an ensemble of alternative possible results for which an entropy can be defined.[1] A theoretical law or relationship is a correlation between ensembles corresponding individually to various measurements and therefore constitutes organization of the system consisting of these ensembles according to the above definition. Theory strives to maximize organization of observation. Of two theories giving equally good representations of a given ensemble of observations the "simpler" is preferred, i.e., the one which is less redundant.

* To be called for at the end of Session V if the Chairman rules that time permits.
[1] J. Rothstein, Science **114**, 171 (1951).

SP2. Information, Thermodynamics, and Time. JEROME ROTHSTEIN, *Signal Corps Engineering Laboratories.**—The communication-measurement analogy[1] yields an informational conception of the first law leading to Caratheodory's form of the second law and interpretation of entropy as missing information without appeal to statistical concepts. The third law is trivially true. Irreversibility of measurement is equivalent to the second law. The positive time direction is distinguished as that permitting information to be acquired (measurements made) about a system of interest (e.g., clock) or equivalently as characterized by entropy increase (information loss) in the wider totality of system of interest plus means of observation. At equilibrium entropy is maximum, no information can be obtained, and symmetry obtains between past and future. For a pure case entropy is zero, no nonredundant information is obtainable without converting the pure case to a mixture, and perfect reversibility again holds; similarly for classical mechanics. Time direction is well defined only for nonequilibrium. Irreversibility of measurement is fundamentally phenomenological rather than quantal in origin.

* To be called for at the end of Session V if the Chairman rules that time permits.
[1] J. Rothstein, Science **114**, 171 (1951).

SP3. On the Boundary Layer Theory in Hypersonic Flow in Rarefied Gases. M. Z. v. KRZYWOBLOCKI, *University of Illinois* (Introduced by Charles Fletcher).*—Equations of motion consisting of the first three approximations developed by the kinetic theory of nonuniform gases are assumed to correctly describe the motion in hypersonic flow in rarefied gases. The kinetic theory of gases gives in addition to known terms in Navier-Stokes equations higher order terms which represent complicated additional stresses and heat flux in the equations of motion and energy. The paper analyses the boundary layer equations in a two-dimensional flow under the assumption that higher order terms should be considered. A new method of solving the complicated system of partial differential equations is derived. By a suitable transformation the foregoing set is transformed into a set of ordinary differential equations with the preservation of a quasi-one-to-one relation. In the final step differential analog must be used.

* To be called for at the end of Session L if the Chairman rules that time permits.

Author Index to Papers Presented at the Annual Meeting