Proceedings of the American Physical Society

MINUTES OF THE MEETING AT CHICAGO, OCTOBER 24–27, 1951

THE American Physical Society is not accustomed to taking a back seat at joint meetings; but in October, 1951, in Chicago it gladly did so, according the front seat and the spotlight to the American Institute of Physics which was celebrating its vigintennial. For several years our conventions at New York and at Washington have systematically been the largest assemblies of physicists that ever took place anywhere: but now we yield the palm to the Institute, which amassed no fewer than 3500 registrations, gathered 3000 people into the Civic Opera House during Thursday October 25, and assembled 850 at the banquet on Thursday evening. Fourteen hundred and fifty-eight of the registrants admitted to membership in our Society; it is to be presumed that many others conceded the fact by omission from their registration cards. A description of these affairs is published in *Physics Today*. The office of the Society is not displeased by the fact that, for once, the work of administering the meetings fell on other shoulders than those of its own deputies, and the University of Chicago got a well-deserved vacation from its annual stint of playing host to us. The Secretary publishes his personal gratitude to Mr. Wallace Waterfall and Miss Ruth Bryans for supervising the publication of the Chicago *Bulletin* and to Messrs. R. M. Bozorth, G. E. Moore, Gerald Oster, E. O. Salant, A. L. Schawlow, and R. L. Serber for distributing the papers into sessions.

The program of the meeting is republished here exactly as it stood in the Bulletin, with a subsequent page of errata. As it makes clear, the meetings of our Society were held on Wednesday afternoon (October 24) and on Friday and Saturday. Those held on Thursday are also listed here, but the credit for these belongs to the Institute.

The Council of the Society met on Friday evening. It elected to Fellowship Seymour Bernstein, S. K. Haynes, C. G. Shull, and J. A. Van den Akker, and to Membership three hundred and thirteen candidates whose names are appended. G. B. Pegram and C. C. Lauritsen were nominated for three-year terms to the Governing Board of the American Institute of Physics; K. K. Darrow and H. H. Nielsen were appointed to the United States National Committee of the International Union of Pure and Applied Physics. Preliminary steps were taken toward an elevation of dues, page charge (for articles in *The Physical Review*), and subscription rate of *The Physical Review* to nonmembers of the Society. This is necessitated by the continuing expansion of *The Physical Review* and rise in the unit costs of publication, which have already been reflected in a serious deficit incurred by the Society in its 1951 operations.

Elected to Membership: Abraham Abramowitz, Hans Aeppli, Pierre R. Aigrain, Heinz Albers-Schoenberg, Kurt Alder, Gentaro Araki, James S. Arthur, William R. Atkinson, Stanley Backer, Leo L. Baggerly, Silvio J. Balestrini, David A. Barge, Robert L. Barringer, Alexander Basil, Chester F. Bass, Theodore Baurer, Robert L. Becker, Stewart Becker, Arthur Beiser, Frank P. Beitel, Jr., Martin Berger, Martin J. Berger, Arthur I. Berman, Virgil J. Barry, Jr., Satyendra K. Bhattacherjee, Hans Bichsel, Frank E. Bjorkland, Nicolaas Bloembergen, Mortimer C. Bloom, Louis P. Bolgiano, Jr., Jose V. Bonet, S.J., Joseph R. Bookee, Robert S. Bradford, William T. Brahmstedt, Carter D. Broyles, Charles E. Buchwald, Lauren H. Bullis, James L. Burkhardt, Clyde R. Burnett, Antonio E. P. Cabral, Ilse R. Callomon, Richard H. Capps, John G. Carver, Harvey Casson, Victoria G. Castro, Chia-hua Chang, Raymond M. Chang, Russell H. Christian, Morton L. E. Chwalow, Edward N. Clarke, Harold E. Clearman, Joseph Cohen, James A. Collinson, A. Allen Comstock, Claude E. Cooke, Jr., C. Dewey Cooper, John J. Corrigan, Jerry A. Cowen, James L. Cox, Glenn A. Crosby, Frances R. Culver, James B. Cumming, Sperry E. Darden, Jr., Henry C. Daubert, Jr., Paul O. Davey, Abram Davis, William E. Deeds, Clive O. De Long, Jr., Robert L. Doan, Douglas J. Donahue, William R. Drake, James A. Dreesen, Victor W. Drexelius, James E. Drummond, Lawrence Dunkelman, Jerome Eckerman, Walter F. Edgell, Donald A. Edwards, Samuel F. Edwards, David F. Eggers, Henry Ehrenreich, Yehuda Eisenberg, Charles Ekstein, Bruce V. English, Walter Shaffer Ernst, Jr., Daryl D. Errett, Harold P. Eubank, George E. Evans, Robert G. Evans, William H. Evans, James E. Faulkner, Ralph Feder, George Feher, Joseph Feinstein, Robert L. Feldmann, Seymour I. Finkel, George W. Ford, Roberto I. M. G. Forneris, John David Fox, Wilfred D. Francis, Eli H. Freedman, William F. Fry, Hiroshi Fuknda, John W. Gardner, Isadore L. Gelles, Mervin H. Gilbert, Edward W. Girard, Allen N. Goland, Jose Goldemberg, Myron L. Good, James M. Goode, Shigeo Goto, Gordon R. Gottloeb, William H. Gust, Melvin N. Hack, Jay E. Hammel, Richard W. Hannum, Donald F. Hansen, Francis H. Harlow, Jr., William H. Harwood, William B. Hawkins, Jr., Miles V. V. Hayes, George E. Hays, Richard I. C. Hede, Richard M. Hedges, Ernst Heer, Robert Herr, Earl W. Hessee, Kenneth A. Hoagland, David S. Hoffman, Jack M. Hollander, Charles W. Hoover, Jr., Arnold Honig, Nahmin Horwitz, Yu-Chang Hsieh, Edward J. Huibregtse, Floyd B. Humphrey, William H. Hyslop, George J. Igo, Takehiko Ishizu, Theodore Jarvis, Louis R. Jauneau, David Jeffries, Robert G. Johnson, William Bruce Johnson, Friedrich A. Kaempffer, George Dewitt Kahl, Selig Kainer, Susumu Kamefuchi, Evan O. Kane, Arnold M. Karo, Rokuo Kawabe, Heiji Kawai, William J. Kearns, David T. Keating, Frederic Keffer, Paul J. Kellogg, William H. Kelly, Vincent P. Kenney, Arthur K. Kerman, Maung M. Kha, Ryoichi Kikuchi, Ki-ichi Kimura, Vivian Kramer, Donald E. Kreinheder, Theodore J. Krieger, John A. Kurtz, Robert H. Land, Thomas W. Layton, Richard D. Leamer, Robert J. Lee, Jack R. Leibowitz, Andrew W. Lennert, Paul J. Leurgans, Walter F. Leverton, Irving E. Levy, Sheldon L. Levy, Robert Lindsay, David E. Little, John T. Lund, Jr., William G. Machell, Robert P. MacKenzie, Robert J. Mackin, Jr., Karl G.

Malmfors, Donald E. Maxwell, John E. May, Jr., Endre A. Mayer, Carlyle D. McKay, Jack McLain, William D. McCoy, William H. Meiklejohn, Eric E. Metzger, Norman J. Meyer, Aubrey B. Mickelwait, Vaden W. Miles, James W. Miller, Leston W. Miller, Frederick E. Mills, Robert G. Mills, Yang L. Ming, San-ichiro Mizushima, Alvie O. Mooneyham, Jr., Donald P. Moore, Peter G. Moore, Bernard Mozer, Lyman Mower, Thomas R. Munson, John L. Need, Ronald G. Newburgh, William J. Noble, Koreichi Ogata, Walter T. Ogier, Raymond S. Ogrinc, Mladen Paic, Lowell S. Pelfrey, James R. Peterson, Thomas E. Petriken, Sebastian Pietropinto, Sergio P. Porto, Francisco E. Prats, Harold R. Raemer, Ernest C. Ray, W. Thornton Read, Jr., Howard L. Recht, Kenneth B. Rhodes, James W. Riggs, Jr., Hugh G. Robinson, Myron Robinson, Charles E. Roland, William S. Rothwell, Virginia V. Royden, Walter Rosenzweig, Sidney Ross, Benjamin Roth, James J. Ruddick, S.J., Klaus Ruedenberg, Lauren J. Rueger, Veikko R. Saari, Mendel Sachs, Harvey G. Safren, Kermit L. Sandefur, Aaron P. Sanders, Frederick L. Scarf, Henry F. Schaf, Jr., Edwin J. Scheibner, Lloyd E. Schilberg, Aurel M. Seifert, Duane C. Sewell, Robert L. Shacklett, Charles B. Shaw, Jr., Sol Skolnik, Bowen E. Simmons, W. Eugene Sinner, Edward F. Smiley, II, Francis F. Skiba, Donald C. Smith, Lyman A. Smith, Richard K. Smyth, Frank T. Solmitz, Hal L. Sowers, M. Lynn Stevenson, Donald H. Stork, Roger A. Strehlow, Seiichi Sueoka, Herbert J. Sukenik, Ivan Supek, Robert M. Sweet, Shuji Takagi, Hideo Takaki, John G. V. Taylor, Donald J. Tendam, Lee C. Teng, Carl D. Thurmond, Jay Todd, Jr., Carl Tatsuo Tomizuka, Frank M. Trantham, Jr., Jacques P. Trembley, Kenneth R. Trigger, George H. Trilling, Hiroomi Umezawa, Minoru Umezawa, Victor A. J. van Lint, James F. Vedder, Alfred R. Vernon, Frederick LeRoy Voelz, Paul F. Wacker, Wilhelm Walcher, LeRoy Walters, Jr., Joe W. Warmuth, William D. Warters, Monroe S. Wechsler, George H. Weiss, Gottfried K. Wehner, LeRoy Dougherty Weld, James A. Weinman, John R. Welty, James A. Whalen, Marian N. Whitehead, Tracy F. Wichmann, Charles H. Wilcox, Lee R. Wilcox, J. Norton Wilson, Robert N. Wilson, John A. Winfrey, Murray M. Winn, Henry H. Woodbury, Ervin C. Woodward, Jr., Sadaaki Yanagawa, Donald E. Young, Tom J. Ypsilantis, Theodore Zang, Harold W. Zeoli, and Sigurd Zienau.

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

Errata Pertaining to Papers C1, C11, E11, H2, H12, I1, I6, I9, I10, I11, P1, and SP1

C1, by R. E. Fox, W. M. Hickam, T. Kjeldaas, Jr., and D. J. Grove. In line 16, $V_R+\Delta_R$ should read $V_R+\Delta V_R$.

C11, by Gilbert W. King. A footnote should be added, reading "This work was sponsored by the ONR under Contract No. N6-onr-228, T. O. II, Project NR 033 243."

E11, by Robert S. Livingston. In line 19, assembyl should read assembly.

H2, by M. M. Block, S. Passman, and W. W. Havens, Jr. In Table I, the results for D and Pb should read:

$2.9\pm1.2\times10^{-28}$ cm^2 sterad^{-1} $1.1\pm0.9\times10^{-28}$ cm^2 sterad^{-1}

$15\pm3.7\times10^{-28}$ cm^2 sterad^{-1} $3.5\pm1.7\times10^{-28}$ cm^2 sterad^{-1}

H12, by S. B. Treiman. In the last sentence, 20 and 600 8-cm^{-2} should read 200 and 600 g-cm^{-2}.

I1, by Peter Havas. Footnote 2 should read H. Steinwedel, S.-B Heidelberger Akad. Wiss., . . . instead of H. Steinwedel and S.-B Heidelberger, Akad. Wiss., ...

I6, by E. J. Schremp. In line 13, and should read an. In line 17, varities should read varieties.

I9, by Frederik J. Belinfante. In line 11, $\mathfrak{a}=\mathfrak{A}-\mathbf{U}_{II}$ should read $\mathfrak{a}=\mathfrak{A}-\mathbf{U}_{\perp}$. In line 16, $\mathfrak{E}=\mathfrak{E}+\mathbf{E}_{II}$ should read $\mathbf{E}=\mathfrak{E}+\mathbf{E}_{II}$.

I10, by Jerome Rothstein. In lines 8 and 9, measurement or observation of objects to grouping them in classes should read measurement or observation of objects leads to grouping them in classes. In reference 1, Phys. Rev. **82**, 322 (A) (1951) should read Science **114**, 171 (1951).

I11, by B. Liebowitz. In the formula for α $\left[1+\frac{4e}{Nm}\left(\frac{3}{2G}\right)\right]^{\frac{1}{2}}$ should read $\left[1+\frac{4e}{Nm}\left(\frac{3}{2G}\right)^{\frac{1}{2}}\right]^{\frac{1}{2}}$.

P1, by Donald H. Jacobs, Michael May, and Seymour Scholnick. The name of Michael May should be deleted from the list of authors.

SP1, by Frederik Belinfante. In lines 13 and 14, $\delta tx(x')$ should read $\delta t(x')$. In line 15, $\mathfrak{E}\equiv\mathbf{D}-4\pi\mathbf{P}$ should read $\mathbf{E}\equiv\mathbf{D}-4\pi\mathbf{P}$.

PROGRAMME

WEDNESDAY AFTERNOON AT 2:00

Morrison, Roosevelt Room

(R. S. MULLIKEN presiding)

Programme of the Division of Chemical Physics

AA1. Some Contributions to the Theory of Molecular Structure. JOHN E. LENNARD-JONES, *Cambridge University.* (45 min.)

AA2. The Photochemistry of Condensed Systems as Illustrated by the Optical Sensitization of the Photographic Emulsion. W. WEST, *Kodak Research Laboratories.* (45 min.)

AA3. The Theory of the Critical Point. BRUNO H. ZIMM, *General Electric Research Laboratories.* (45 min.)

THURSDAY MORNING AT 9:30

Chicago Civic Opera House

(GEORGE R. HARRISON presiding)

Joint Symposium on Physics Today with the Member Societies of the American Institute of Physics

The Nucleus. ENRICO FERMI, *University of Chicago.*
The Atom. E. U. CONDON, *Corning Glass Works.*
The Solid State. J. C. SLATER, *Massachusetts Institute of Technology.*

THURSDAY AFTERNOON AT 2:00

Chicago Civic Opera House

(GEORGE R. HARRISON presiding)

Joint Symposium on Physics Today (continued)

Acoustics. HARVEY FLETCHER, *Columbia University.*
Optics. EDWIN H. LAND, *Polaroid Corporation.*
Physics as Science and Art. K. K. DARROW, *Bell Telephone Laboratories.*

THURSDAY EVENING AT 7:30

Hotel Sherman, Grand Ballroom

(PAUL E. KLOPSTEG presiding)

Joint Banquet with the Member Societies of the American Institute of Physics

(Title to be announced). KARL T. COMPTON, *Chairman of the Corporation, Massachusetts Institute of Technology.*

(Title to be announced). THE HONORABLE BRIEN MCMAHON, *U. S. Senator from Connecticut.*

FRIDAY MORNING AT 9:30

Sherman, Louis XVI Room

(S. K. ALLISON presiding)

Nuclear Scattering

A1. The Theory of Neutron Scattering by Gases. N. K. POPE AND G. FELDMAN, *Chalk River Laboratory.*—The calculation of the differential cross section for neutron scattering by gas molecules requires summations over all the initial and final states of the molecule. For rigid molecules with infinite mass and infinite moment of inertia, the cross section can be reduced to a simple form analogous to that used in the scattering of x-rays.[1] However, even when allowance is made for the vibration of the nuclei,[1] the simplified expression gives a poor representation of the experimental cross sections for molecules such as H_2 and CH_4. A better approximation to the cross section has been obtained as an expansion in powers of two parameters, *viz.*, the ratio of the neutron mass to the molecular mass, and the ratio of the energy of the first excited rotational state to the energy of the incident neutron. Differential cross sections have been calculated for diatomic and spherical top molecules and have been compared with experimental results.

[1] N. K. Pope, Royal Society of Canada, June meeting, 1951, Paper 75.

A2. Scattering by Bound Particles with Short-Range Interaction Force. H. EKSTEIN, *Illinois Institute of Technology.*—For forces which are large over a small distance, Born's approximation is unsatisfactory. An alternative expansion is obtained by transforming the scattering equations so that the interaction potential is eliminated and replaced by a matrix α which describes the scattering by a *fixed* particle, in a manner analogous to that used in the discussion of multiple scattering by fixed centers.[1] The rigorous equation so obtained can be solved by iteration. The first approximation is formally the same as Born's first approximation, with α replacing the interaction potential between incident particle and scattering particles, but the higher approximations are different; in particular, they are convergent for the limiting case of point scatterers, where the second Born approximation diverges. For this particular case of point scatterers, the first approximation is identical with the result obtained by Fermi for the scattering of neutrons by bound protons.

[1] H. Eckstein, Phys. Rev. **83**, 721 (1951).

A3. Regular Meson Type Potentials in Proton-Proton Scattering.* R. D. HATCHER AND H. E. HART,† *New York University.*—Results of low energy proton-proton scattering using a meson potential give a mass for the π-meson[1] (316 times the mass of the electron) which is larger than that observed experimentally (275 m). Calculations show that a modification of the potential used will give results agreeing with the lower value. The potential used has the form $V=(1-e^{-x})(1/x-Ce^{-2x}/x)mc^2$ where C is a pure number parameter, and x is mc^2r/e^2. This potential has in addition the property of being everywhere finite. Alternate forms of these meson type potentials will be considered. Perturbation calculations which show the effect of the nuclear distance coulomb modification on the hydrogen atom and other applications will be discussed.

* This work was supported by the ONR.
† On leave of absence, Board of Education, New York City.
[1] G. Breit and R. D. Hatcher, Phys. Rev. **78**, 110 (1950).

A4. Total Cross Sections of Carbon and Hydrogen for 14-Mev Neutrons.* H. L. POSS, E. O. SALANT, AND L. C. L. YUAN, *Brookhaven National Laboratory.*—Carbon and hydrogen total cross sections for 14-Mev neutrons[1] were redetermined to a probable error of 1 percent. Thick zirconium-tritium targets were bombarded by 400-kev deuterons of Department of Terrestrial Magnetism's electrostatic generator. Neutrons were detected by a terphenyl-xylene scintillation counter, efficiency 5 percent.[2] They were monitored by counting the alpha-particles from the reaction. Source to detector distance: 40 in.; scatterer diameter: 1 in., so that only 0.2 percent of incident neutrons were scattered into detector for the thickest scatterer. Counting rate was about 2000/min. Neutron background of 6 percent was determined with 13-in. copper cylinder in neutron beam. A least-squares analysis of the transmission of six thicknesses each of carbon and polyethylene (40 to 85 percent transmission) gives the following total cross sections: $\sigma_C=1.279\pm0.004$ b, $\sigma_A=0.689\pm0.005$ b for an effective neutron energy evaluated to be 14.08 ± 0.05 Mev.[3]

* Research carried out under the auspices of the AEC.
[1] E. O. Salant and N. F. Ramsey, Phys. Rev. **57**, 1075 (1940). Ageno, Amaldi, Bocchiarelli, and Trabacchi, Phys. Rev. **71**, 20 (1947). W. Sleator, Phys. Rev. **72**, 207 (1947).
[2] Falk, Poss, and Yuan, Phys. Rev. **83**, 176 (1951).
[3] G. Snow, following abstract.

A5. Analysis of 14-Mev $n-p$ Scattering.* GEORGE SNOW, *Brookhaven National Laboratory.*—The total S-wave $n-p$ scattering cross section can be written[1]

$$\sigma^{(s)}_{\text{total}}=\sigma_{\text{triplet}}+\sigma_{\text{singlet}}$$
$$=\frac{3\pi}{[k^2+(\alpha_t-\frac{1}{2}\rho_t k^2)^2]}+\frac{\pi}{[k^2+(\alpha_s-\frac{1}{2}\rho_s k^2)^2]}. \quad (1)$$

α_t, r_{0t}, and α_s are determined from low energy data. Hence $\sigma^{(s)}_{\text{total}}$ is a function of unknown effective singlet range, r_{0s}, for an assumed well shape, if neutron energy is known. The neutron energy distribution from the $D-T$ reaction used above[2] has been calculated. 95 percent of the neutrons have relativistic kinetic energies between 13.88 and 14.23 Mev, and $[\langle(1/En)\rangle]^{-1}=14.08\pm0.05$ Mev. From experimental $n-p$ cross section[2] and Eq. (1), r_{0s} has been obtained for three choices of potential well shape; square (S), exponential (E), and Yukawa (Y). Exact S-wave phase shifts have also been calculated and resultant small corrections to $\sigma^{(s)}$ of Eq. (1) have been made. Results are $r_{0s}=2.23\pm0.25(S)$, $r_{0s}=2.28\pm0.33(E)$, $r_{0s}=2.29\pm0.40(Y)$.

* Research carried out under the auspices of the AEC.
[1] J. M. Blatt and J. D. Jackson, Phys. Rev. **76**, 18 (1949).
[2] Poss, Salant, and Yuan, preceding abstract.

A6. The Scattering of 30-Mev Alpha-Particles by Helium.* E. GRAVES,† *Massachusetts Institute of Technology.*—The angular distribution of elastic scattering of 30-Mev alpha-particles by helium has been measured using the emergent beam of the MIT cyclotron. The distribution has structure with broad maxima in the regions of $\theta'=53°$ and 90° in the center-of-mass system and minima at $\theta'=40°$ and 70° and rises strongly forward of $\theta'=40°$. Scattered alpha-particles were detected with a triple proportional counter, which could be rotated within a 2-foot diameter scattering chamber filled with helium. The absolute differential cross section was measured by comparison with the scattering from an Au foil target to be $(2.8\pm1.4)\times10^{-26}$ cm²/steradian at $\theta'=83.3°$. It has been suggested that the maxima and minima appear indicative of a well-defined diffraction of the DeBroglie wave amplitude associated with the motion of the alpha-particles by the interaction potential between them.

* This work has been assisted in part by the joint program of the ONR and AEC.
† Major, USA, assigned as student at MIT.

A7. Classification of Levels in Al^{25}.* L. J. KOESTER,†‡ *University of Wisconsin.*—A phase shift analysis[1] of the elastic scattering of protons by Mg^{24} has been completed. This work has yielded information regarding the angular momentum and parity quantum numbers of levels observed in Al^{25}. In the region of bombarding energies between 0.4 and 3.4 Mev, the general trend of the differential scattering cross section is well fitted by a combination of the effects of potential scattering (including coulomb) and of the three observed broad resonances. The parities, relative to Mg^{24}, of most of the narrow resonances are determined. A twofold ambiguity remains in their angular momentum quantum numbers because the experimental resolution was not sufficient to give the true maximum cross sections of the very narrow peaks. These excited states of Al^{25} are considered from the viewpoint of the shell model of the nucleus.

* Work supported by the AEC and the Wisconsin Alumni Research Foundation.
† AEC Predoctoral Fellow.
‡ Now at University of Illinois, Urbana, Illinois.
[1] Koester, Goldberg, Kaufmann, Mooring, and Saxon, Phys. Rev. **83**, 219(A) (1951).

A8. Precision Scattering Project.* JAMES S. ARTHUR, A. J. ALLEN, R. S. BENDER, R. L. ELY, H. J. HAUSMAN, L. A. PAGE, AND E. M. REILLEY, *University of Pittsburgh.*—A description is given of the performance of the apparatus for the Precision Scattering Project at the University of Pittsburgh. The scattering chamber is located in a subterranean room built in the hillside adjacent to the cyclotron. An 8-foot wall serves as shielding between the cyclotron and scattering room. A 6-ton focusing electromagnet directs the beam from the 47-inch cyclotron into the underground room through the shielding. A 40° uniform field, magnetic analyzer provides a beam of 0.5 microampere of 8-Mev protons with energy spread ±10 kev through $\frac{1}{16}$th inch analyzing slits. A similar magnet can be rotated about the target to analyze charged product particles of nuclear reactions at angles from 0° to 150°. Trimming and calibrating the magnets were achieved using polonium alpha-particles (values reproducible with a probable error in momentum of ±0.04 percent). The magnetic fields are electronically regulated and measured by the nuclear magnetic resonance method to better than 1 part in 5000.

* Work done in the Sarah Mellon Scaife Radiation Laboratory and assisted by the joint program of the ONR and AEC.

A9. Energy Levels in Al^{27}. E. M. REILLEY, A. J. ALLEN, J. S. ARTHUR, R. S. BENDER, R. L. ELY, AND H. J. HAUSMAN, *University of Pittsburgh.**—Twenty-two energy levels in Al^{27} have been found by the magnetic analysis of inelastically scattered protons at 90° from thin targets of aluminum. An analyzed beam of 8.0-Mev protons was utilized for the bombardment. Tentative values for the levels found are 0.810, 0.985, 2.253, 2.571, 3.041, 3.377, 3.727, 3.931, 4.008, 4.108, 4.288, 4.464, 4.568, 4.638, 4.864, 4.988, 5.110, 5.212, 5.352, 5.496, 5.560, and 5.615 Mev. A broad alpha-particle group from the $Al^{27}(p, d)Mg^{24}$ reaction corresponding to an excited state of Mg^{24} was also observed and is believed to be complex.

* Work done in the Sarah Mellon Scaife Radiation Laboratory and assisted by the joint program of the ONR and AEC.

A10. Inelastic Scattering of Protons from Nickel.* RALPH ELY, JR., A. J. ALLEN, J. S. ARTHUR, R. S. BENDER, H. J. HAUSMAN, AND E. M. REILLEY, *University of Pittsburgh.*—Using the equipment developed for the Precision Scattering Project at the University of Pittsburgh, inelastic scattering of 8-Mev protons from a thin nickel target has been observed at 90°. The sixteen energy levels obtained for natural nickel are 1.338, 1.475, 2.185, 2.497, 2.660, 2.812, 2.945, 3.083, 3.162, 3.227, 3.308, 3.465, 3.567, 3.642, 3.824, 3.943 Mev. At present, only the three levels 1.338, 1.475, 2.497 Mev can be assigned to nickel 60 from comparison with beta-decay of cobalt 60.

* Work done in the Sarah Mellon Scaife Radiation Laboratory and assisted by the joint program of the ONR and AEC.

A11. Total Cross Sections of Heavy Nuclei for Fast Neutrons.* D. W. MILLER,† R. E. FIELDS, AND C. K. BOCKELMAN, *University of Wisconsin.*—The total cross sections of twenty-three heavy nuclei from iron to bismuth were determined as a function of neutron energy. Monoenergetic neutrons in the energy range from 0.02 to 3.2 Mev were obtained by bombardment of thin lithium or Zr-T targets with protons from the electrostatic generator. Total cross sections of the closed-shell nuclei strontium, yttrium, barium, lanthanum, cerium, and praseodymium were measured at intervals of 0.02 Mev from 0.02 Mev to 1.4 Mev, and at about 0.15-Mev intervals from 1.4 Mev to 3.2 Mev. Using somewhat wider point separations, niobium and molybdenum were investigated from 0.1 Mev to 3.2 Mev. In addition, earlier results obtained at Wisconsin below 1.4 Mev for fifteen other heavy nuclei were extended to 3.2 Mev using about 0.15-Mev spacing between points. A broad maximum occurs in the total cross sections of the heavier elements. This maximum appears to move to higher neutron energies with increasing mass number.

* Work supported by the AEC and the Wisconsin Alumni Research Foundation.
† AEC Predoctoral Fellow.

A12. The Calculation of High Energy Scattering Cross Sections Using Variational Methods.* DAVID S. SAXON, *National Bureau of Standards* AND E. GERJUOY, *University of Southern California.*—High energy elastic scattering by a square well and by a Yukawa potential have been calculated using variational methods.[1] The actual application of these methods depends, of course, upon the evaluation of rather intricate integrals involving products of trial functions and the Green's function. For a trial function which consists of a plane wave with a suitably modified wave number in the interior of the scattering potential, the integrals can be evaluated in closed form, at least for forward scattering, and hence a rather simple expression can be obtained for the total cross section. The results are strikingly better than the Born approximation as indicated by comparison with exact calculations. As an example, for neutron-proton square well scattering, the variational results are within a few percent of the exact results of Camac and Bethe[2] over the energy range from 20 to 80 Mev. The extension to the case of exchange forces will be discussed.

* The preparation of this paper was sponsored (in part) by the ONR.
[1] J. Schwinger, hectographed notes on nuclear physics, Harvard (1947).
[2] M. Camac and H. A. Bethe, Phys. Rev. **73**, 191 (1948).

FRIDAY MORNING AT 9:30

Sherman, West Room

(N. S. GINGRICH presiding)

Electron Physics

B1. The Effect of the Thermal Velocity Distribution upon the Behavior of Diodes at Microwave Frequencies. P. PARZEN, *Federal Telecommunication Laboratories, Inc.*—Hahn[1] has shown that it is possible to account for the effect of the thermal velocity distribution on the dc properties of diodes by including a pressure term in the equation of motion. It is possible to

extend this method to higher frequencies and thereby compute the ac impedance and noise fluctuations of diodes. The results obtained by this method will be compared to those of Llewellyn[2] and Rack.[3] One of the fundamental results is that the process being classified as low or high frequency depends upon whether the frequency is much smaller or much larger than the plasma frequency at the virtual cathode.

[1] W. C. Hahn, Proc. Inst. Radio Engrs. **36**, No. 9, 1115 (September, 1948).
[2] F. B. Llewellyn, *Electron Inertia Effects* (Cambridge University Press).
[3] A. J. Rack, Bell System Tech. J. **17**, No. 4, 592 (October, 1938).

B2. On the Influence of Field on Temperature Saturated Emission from Semiconducting Cathodes. K. LEHOVEC, *Signal Corps Engineering Laboratories.*—The negative charge induced on a semiconducting cathode by an applied field may spread over a layer of many lattice spacings thickness. The corresponding potential may amount to several tenths of a volt, modifying the work function of the cathode. The voltage V across the space charge layer was calculated as function of applied field F for the case of positively and negatively charged surface states, respectively, and for full, or partial, or weak ionization of surface states, assuming quasithermal equilibrium conditions and an n-type semiconductor with weakly ionized donors. Under certain conditions the slope of the Schottky-lines may reach values as high as $dV/dF^{\frac{1}{2}} \approx kT/[e(F^{\frac{1}{2}})]$, which is for $F \approx 100$ volt/cm and $T \approx 1000°$K nearly two orders of magnitude larger than the slope calculated from deformation of image force potential by applied field.* Thus, the deformation of space charge potential may explain the large "Schottky"-slopes occasionally observed on oxide-coated cathodes, and constitutes an alternative explanation to that based on patch effects.

* W. Schottky, Physik Z. **15**, 872 (1914).

B3. A Retarding Potential Method of Measuring the Electrical Conductivity of Oxide Coated Cathodes.* I. L. SPARKS,† *University of Missouri.*—A retarding potential method has been used to study the electrical conductivity of BaO-coated cathodes. This method, which involves a determination of the voltage drop across the coating as thermionic emission is being drawn from the coating, permits conductivity measurements without the use of probes. In a similar method used by Young and Eisenstein[1] it was assumed that the Schottky lowering of the potential barrier at the surface of the cathode was negligible compared with the voltage drop across the coating and that the method was applicable for a wide range of anode voltages. In the study reported here a method is developed which does not involve these assumptions. This method can be used for coatings whose thermionic emission to conductivity ratio is greater than 0.5 volt/cm. Advantages and disadvantages of the method will be given. It is found the slope of the retarding potential curve is less than the expected value, $-e/kT$. A possible explanation of this is given.

* This work supported in part by the ONR.
† Now at Eastern Illinois State College.
[1] A. Eisenstein and J. R. Young, Phys. Rev. **75**, 347(A) (1949).

B4. A Study of Evaporated Films of BaO using Electron Diffraction Techniques.* PAUL RUSSELL, *University of Missouri.*—Electron diffraction techniques have been used previously to study compounds in continuously pumped vacuum systems at pressures of the order of 10^{-6} mm. Since thermionically active films of BaO are stable only at much lower pressures, an all-glass, sealed-off diffraction tube was developed which operates at less than 10^{-8} mm. This tube resembles an elongated cathode ray tube using magnetic focusing and deflection. A spectroscopically pure polished Ni sample is set at grazing incidence to the electron beam, about halfway between the gun and the screen. This sample may be heated to elevated temperatures. Above the sample is a Pt evaporator which contains the source of BaO. A movable Ta anode is inserted between the sample and evaporator for thermionic emission measurements. The diffraction pattern appears on a fluorescent screen and is recorded photographically. The diffraction patterns indicate (1) considerable preferred orientation of the first few monolayers laid down on Ni at 800°K, (2) a marked reduction in thermionic emission and change in pattern after heat treatment up to 1200°K, and (3) reduction in preferred orientation for thicker deposits.

* This work supported in part by the ONR.

B5. Microwave Propagation Through an Electronic Space-Charge in a Magnetic Field.* JAMES R. HOOPER, JR.,† *Harvard University.*—A linearly polarized electromagnetic wave traveling through an electronic space-charge in the presence of a magnetic field, parallel to the direction of propagation, is considered. Since the electronic motion is essentially circular about the magnetic lines of force, it is convenient to resolve the linearly polarized wave into two oppositely rotating circular components. The effect of the electron motion may be treated as a contribution to the apparent dielectric constant of the region, which will be different for each sense of circular polarization. Although high vacuum conditions are assumed, damping effects must be considered for magnetic fields near the cyclotron value because the resonant circular electron motion decreases the mean time between collisions with residual gas molecules. In particular, the case of a wave guide terminated in a space-charge is considered. The reflection coefficient is calculated for each sense of circular polarization, and the plane-polarized components reflected parallel to and normal to the incident polarization are calculated by recombining the reflected circular components. Experimental results for a resonant cavity terminated in an electronic space-charge will be presented.

* This research was supported jointly by the ONR and the Signa Corps under ONR Contract N5ori-76, T.O.I.
† Now at Case Institute of Technology, Cleveland, Ohio.

B6. Liquid-Filled Ionization Chambers. M. A. VAN DILLA,* *Massachusetts Institute of Technology.*—The present experimental work deals with the measurement of the energy dissipation of x-rays and gamma-rays by means of the ionization produced in insulating liquids. The liquid chosen was decane, and a collecting field of about 1000 volts per cm was used. Ions, not electrons, are collected since the electrons produced quickly attach to form negative ions. This means that initial recombination plays an important role and prevents saturation from being achieved. At the field strength used the ion current collection was about 5 percent of the ion production. Even so, the current collection per unit energy flux from a decane-filled ion chamber is 25 to 30 times more than that observed in an ion chamber of identical volume filled with a gas at standard temperature and pressure. Experiments on the variation of initial recombination with the quantum energy of the incident photons showed that Jaffe's theory of columnar recombination was inapplicable, and supported Lea's theory of cluster recombination. The variation of ion current collection with radiation intensity, polarizaing voltage and temperature was also measured, and comparisons with theory were made.

* Present address: Department of Physics, University of Utah, Salt Lake City, Utah.

B7. Photoelectric Thresholds in Photon Counters Containing Electronegative Quenching Gases. H. FRIEDMAN, T. CHUBB, AND D. A. PATTERSON, *U. S. Naval Research Labora-*

tory.—The spectral response of counter tubes to extreme ultraviolet light was measured with the aid of a vacuum monochromator. Observations were limited by the use of LiF windows to wavelengths above about 1050A. The admixture of small amounts of any strongly electronegative gases invariably produced a marked shift of the threshold toward the ultraviolet. Traces of chlorine, bromine, and halogenated hydrocarbons increased photoelectric threshold energies to roughly twice the values of the cathode surfaces in vacuum. Since, in counters containing halogen gases, the ionization potential of none of the gas ions exceeds twice the work function of the cathode, spurious counts due to positive ion neutralization at the cathode surface are largely absent.

B8. Drift Velocity of Electrons in Pure Gases.* D. D. ERRETT† AND F. F. RIEKE, *Purdue University.*—A pulse method for measuring the drift velocity of electrons in gases, described in a previous abstract,[1] has been improved and the apparatus modified so as to permit measurements on gases of high purity. The accuracy is estimated to be 3 percent for the smaller velocities; the errors become somewhat greater for velocities above 4×10^6 cm/sec. Measurements have been made on argon, helium, hydrogen, nitrogen, carbon dioxide, and water vapor. For each gas studied, the velocity proved to be uniquely determined by E/p, the ratio of field strength to pressure (expressed throughout in units of volts/cm/mm Hg). For helium and argon, comparison is made with the drift velocities calculated by Harriet Allen.[2] For helium, the agreement is excellent over the entire range of the calculations ($E/p<4$). For argon, the agreement is close for $E/p<2.5$; at higher field strengths the theoretical values rise above the experimental, presumably because of neglect of inelastic collisions. Rigorous calculations exist for only these two gases. Comparison with previously published measurements shows fairly good concordance of results for He, H_2, N_2, and CO_2. Existing data on water vapor is scanty and in poor agreement with the new results. In the course of measurements on argon, a delayed emission of electrons was observed at the larger values of E/p; this effect is attributed to indirect ionization through the agency of metastable atoms. Evidence was obtained that in water vapor the attachment of electrons to form negative ions is small for $E/p<10$, strong for E/p between 10 and 16, and somewhat less at higher values.

* Assisted by the ONR and AEC.
† Present address: North American Aviation, Inc., Downey, California.
[1] F. F. Rieke and D. Errett, Phys. Rev. **75**, 346(A) (1949).
[2] H. W. Allen, Phys. Rev. **52**, 707 (1937).

B9. Drift Velocity of Electrons in Gas Mixtures.* F. F. RIEKE AND D. D. ERRETT,† *Purdue University.*—The drift velocity of electrons has been measured as a function of E/p in 12 different argon-hydrogen, argon-nitrogen, and argon-carbon dioxide mixtures by the method described in an accompanying abstract.[1] The gas pressures ranged from 100 mm to 10 mm, and measurements were made to $E/p=20$. As is well known, addition of relatively small amounts of a multi-atomic gas to argon can result in a large increase in the drift velocity. For example, with $E/p=1$ the drift velocity in pure argon is 0.38 cm/μsec, in 0.01 H_2−0.99A it is 1.0 cm/μsec, in 0.01N_2−0.99A it is 2.3 cm/μsec, and in 0.01 CO_2−0.99A it is 1.9 cm/μsec. Families of curves are given to show the dependence of drift velocity on gas composition. The relation of the results to the theory of mixtures developed by Townsend and Bailey[2] is discussed.

* Assisted by the ONR and AEC.
† Present address: North American Aviation, Inc., Downey, California.
[1] D. D. Errett and F. F. Rieke, preceding abstract.
[2] Townsend and Bailey, Phil. Mag. **44**, 1033 (1922).

B10. Influence of Irradiation on the Characteristic of a Glow Discharge in Pure Rare Gases. K. W. MEISSNER AND W. F. MILLER, *Purdue University.*—Irradiation of the positive column of a glow discharge in pure rare gases by the radiation from a second discharge tube containing the same gas influences the $V-I$ characteristic of the irradiated glow discharge, shifting it to higher voltage for the same value of current. This effect was described for neon and helium by Meissner and Pierson[1] and new experiments show the same effect with the other rare gases argon, krypton, and xenon. The effect is explained by the presence of metastable atoms. Irradiation by strongly absorbed radiation diminishes the concentration of metastable atoms, removing them as sources of secondary ionization.—In the case of helium it was possible by filtering to study the irradiation effect of the two mainly absorbed lines 10830A and 20851A separately. The whole effect is practically caused by 20851A. This can be understood by considering the possible transitions involved.

[1] K. W. Meissner and R. M. Pierson, Proc. Indiana Acad. Sci. for 1949, **59**, 269 (1950).

B11. The Electric Current between Flashes of the Intermittent Glow Discharge in H_2. HERMAN RITOW, *Northwestern University.*—Measured frequencies in intermittent glow discharges indicate an effective capacity exceeding that ordinarily associated with the circuit. In an effort to evaluate this excess capacity at various pressures, measurements were made of the supply current, the starting and extinction potentials, the period of intermittence, and the external capacity. Graphical analyses of the data indicate that between luminous flashes, a leakage current ("dark current") flows between the electrodes. The average value of this current is constant when the supply current is constant. When the pressure is high the net dark current is in the same direction as the supply. When the pressure is less than that corresponding to the Paschen P×D minimum, it is opposite in direction to the supply current. At very low pressures the returning dark current may be many times the supply, while at very high pressures it may be a large fraction, half or more, of the supply current. Large electrode areas and separations increased the volume of the ionized gas and hence the charge many times over the values usually used in discharge experiments.

B12. Spectroscopic Investigations of Pulsed Gas Discharges.* W. R. ATKINSON, R. G. FOWLER, L. W. MARKS, AND G. W. CHARLES, *University of Oklahoma.*—Pulsed discharges in hydrogen, expanding as fronts into side tubes, were previously† shown to exhibit broadening of the Balmer lines, and intense continua. High resolution spectra show line contours appropriate to Stark broadening. Ion concentrations have therefore been calculated from this broadening by Holtzmark's theory. Maximum values of as much as 10^{17} ions per cc are observed. The magnitude of the maximum is proportional to the initial gas density, and its location is always at some point *in the side tube.* The maximum occurs at an instant in time independent of gas density and firing potential. The continuum beyond the last observable Balmer series member is shown to be of nonmolecular origin by experiments with water vapor. The level of excitation in the fronts is so high that O IV and C IV are observable. Total intensity measurements on H_β as a function of ion concentration have shown the intensity varies as the square of the concentration. This, together with the magnitudes of the observed concentrations, which frequently amount to half the original particle density in the tube, is strongly indicative of radiative recombination.

* Project supported by the ONR.
† R. G. Fowler, *et al.*, Phys. Rev. **82**, 879 (1951).

FRIDAY MORNING AT 9:30

Sherman, Grey Room

(J. E. MAYER presiding)

Chemical Physics

C1. Direct Measurement of Ionization Probability and Appearance Potential Using a Mass Spectrometer. R. E. FOX, W. M. HICKAM, T. KJELDAAS, JR., AND D. J. GROVE. *Westinghouse Research Laboratories.*—A retarding potential V_R is applied to one of the plates so that the low energy electrons are removed from the distribution. By measuring the change in the electron and ion currents when V_R is changed by ΔV_R, one may obtain the ionization probability as a function of the electron accelerating potential V_i, for electrons monoenergetic within ΔV_R. To remove the ions it is necessary to have a field in the ionization chamber. This field and the electron current is given a pulsed time dependence, so that when electrons are moving through the ionization chamber it constitutes a field free region. Space charge is minimized by using a small electron current. The value of V_i for vanishing ion current difference when added to $V_R+\Delta_R$ yields the true appearance potential. Contact potential between the filament and the ionization chamber does not influence this value. Preliminary measurements on a number of gases yielded appearance potentials within 0.1 volt of the spectroscopic value. Circuit improvements are being made in order to obtain increased accuracy.

C2. Van der Waals Forces in Magnetic Fields.* HENRY MARGENAU AND D. E. HARRISON, *Yale University.*—Formulas are worked out for the dispersion forces between molecules satisfying Hund's case *b*, the assumption being that these molecules interact in different magnetic states. In earlier publications, a simplifying average is taken over all magnetic states. This procedure is legitimate for most applications of the theory of Van der Waals forces, but not to the broadening of spectral lines absorbed or emitted in a magnetic field, which has recently been observed with great accuracy by microwave techniques. The work reported here consists mainly in a collection and combination of known matrix elements of the diatomic molecule and results in formulas of considerable complexity. Their numerical evaluation was carried out for O_2. We then inquired whether there is a correlation between the strength of these forces in different magnetic states and the width of lines originating from these states, these widths having been measured by Beringer and Castle.[1] The answer is negative and suggests complications with which the present (second order) theory cannot deal.

* Supported by the ONR.

[1] R. Beringer and J. G. Castle, Phys. Rev. **81**, 82 (1951).

C3. Calculations of the Diamagnetic Susceptibility of N_2. J. V. BONET AND A. V. BUSHKOVITCH, *Saint Louis University.*—The only straightforward quantum-mechanical calculation of the diamagnetic susceptibility of gases carried out so far appears to be that for H_2 by Van Vleck and Frank. We have attempted to calculate the diamagnetic term in the susceptibility of N_2 using a combination of the Fermi-Thomas method as applied to homonuclear molecules by Hund, and the Slater atomic orbital method. The Fermi-Thomas charge distribution is used in the region from the center of the molecule to a distance of 2 angstroms, where this approximation may be expected to be good. From 2 angstroms out, where spherical symmetry may be expected to be a good approximation, Slater atomic orbitals for silicon (double the charge of N_2) are used. The result is 2.3 times the observed value, part of the excess being probably due to the small paramagnetic term. This is a substantial improvement over the straight Fermi-Thomas method which was found, by Sommerfeld, to give ten times the observed result in the case of monatomic gases. The chief cause of the discrepancy is undoubtedly the neglect of the exchange effect in the Fermi-Thomas method. Calculations using the Fermi-Thomas-Dirac equation (with exchange) are in progress. The methods used can be extended to other homonuclear molecules.

C4. Excitation and De-Excitation of the Vibrational Motion of Hydrogen Molecules by Slow Hydrogen Atoms. E. BAUER, *National Research Laboratories.*—An interaction potential between a hydrogen molecule and a hydrogen atom based on one between a hydrogen molecule and an electric charge[1] is used. The cross section is calculated by using the Born approximation and corrected by multiplying it by the square of the ratio of exact to sine wave matrix element of the same process in one dimension.[2] The cross section for de-excitation of the first vibration state, σ_{10}, is obtained from the excitation cross section by using the principle of detailed balance. At gas kinetic energies σ_{10} is of the order 10^{-19} cm^2, so that one in 10^3–10^4 collisions produces de-excitation. The probability of recombination of two hydrogen atoms in a three-body collision in which the two atoms are de-excited from the vibrational continuum to a discrete state of the hydrogen molecule near the continuum is also estimated.

[1] T. Y. Wu, Phys. Rev. **71**, 111 (1947).
[2] E. Bauer, Phys. Rev. (to be published).

C5. Raman and Infrared Spectral Data, Force Constants, and Thermodynamic Properties for Dibromodichloromethane. ABRAM DAVIS, FORREST F. CLEVELAND, AND ARNOLD G. MEISTER, *Illinois Institute of Technology.*—Raman displacements, semiquantitative relative intensities, and precise depolarization factors were obtained for liquid CBr_2Cl_2. The infrared wave numbers for both liquid and gaseous CBr_2Cl_2, in the region 400 to 4000 cm^{-1}, also have been determined, using a Beckman IR-2 (KBr optics) spectrometer. Present values for these spectral data were compared with the results of the two previous investigators in order to decide upon the most probable values of the fundamentals. The values adopted for these were 154, 175, 230, 242, 262, 380, 684, 734, and 770 cm^{-1}, which agree very well with those of Delwaulle and Francois (1942), but differ considerably with those given by L. Lecomte, Volkringer, and Tchakirian (1937). The Wilson *FG* matrix method was used to calculate wave numbers corresponding to the vibrational frequencies, using force constants taken from CBr_4, CBr_3Cl, $CBrCl_3$, and CCl_4. Modification of these force constants led to calculated wave numbers which were within 1 cm^{-1} of the observed values. The observed fundamentals were then used to calculate heat content, free energy, entropy, and heat capacity for 12 temperatures from 100° to 1000°K to a rigid rotator harmonic oscillator approximation.

C6. Decomposition of Di-*t*-butyl Peroxide and Kinetics of the Gas Phase Reactions of *t*-butoxy Radicals in the Presence of Ethylenimine. DAVID H. VOLMAN AND ROBERT K. BRINTON, *University of California at Davis.*—The reaction of di-*t*-butyl peroxide with ethylenimine has been studied between 129° and 154°C. The *t*-butoxy radicals formed by the rupture of the O—O bond of the peroxide are postulated to enter into the

following reactions: decomposition into acetone and methyl radical, recombination of two methyl radicals to form ethane, abstraction of an H atom from the imine by methyl radical to form methane, and abstraction of an H atom from the imine by *t*-butoxy radical to form *t*-butyl alcohol. For the unimolecular decomposition of the peroxide into *t*-butoxy radicals an activation energy of 37.6 kcal per mole and a frequency factor of 3.5×10^{15}/sec are obtained. The capture of imine H atom by methyl radical is found to have an activation energy of 4.8 kcal/mole and a frequency factor of 4.5×10^{10} cc/mole/sec. The activation energy for the thermal decomposition of *t*-butoxy radical into acetone and a methyl radical is about 17 kcal/mole.

C7. Infrared Absorption by Asymmetrical Spectral Lines.* GILBERT N. PLASS AND DOUGLAS WARNER, *The Johns Hopkins University.*—Many recent theoretical investigations have studied the shape of pressure broadened spectral lines. Lindholm has shown that with Van der Waals forces the lines are asymmetrical, at low pressures the absorption coefficient, k, varying as $(\nu-\nu_0)^{-3/2}$ and $(\nu-\nu_0)^{-7/3}$ in the red and violet wings respectively. We have calculated the fractional absorption coefficient, A, for a single asymmetrical line and for a band with asymmetrical lines of equal spacing and intensity. The results are particularly simple for a single line. If k varies as $(\nu-\nu_0)^{-n}$ in the wings of a line, than A is proportional to $(S\alpha u)^{1/n}$. This is the usual square root law for the Lorentz shape ($n=2$). For the Lindholm shape, A is the sum of two terms with appropriate values of n. The results which will be discussed show that the possible asymmetry of the line can be observed by measurements of A. In bands such as 15μ CO_2 and 50μ H_2O the continuous background from the wings of a few strong lines makes an appreciable contribution to the absorption, which is considerably different over wide frequency intervals for symmetrical and asymmetrical lines.

* This work supported by the ONR.

C8. Computation of Infrared Intensities. FRANK MATOSSI, *Naval Ordnance Laboratory.*—Numerical values for the effective charges (defined as $d\mu/dr$, μ = dipole moment, r = atomic distance) of vibrating molecules have been obtained experimentally from intensity measurements.[1] These values can be calculated theoretically from a classical model of the molecular dipole which considers the effect of induced atomic dipoles. The observed effective charges are obtained if the atomic polarizabilities α are assumed to be dependent on the atomic distance. $d\alpha/dr$ as determined from $d\mu/dr$ is in qualitative agreement with values obtained previously from Raman effect data. The results are given for the molecules CO, NO, CO_2, CS_2, OCS.

[1] For instance, D. Z. Robinson, J. Chem. Phys. **19**, 881 (1951).

C9. Theory of Dielectric Dispersion. MARIUS COHN, *University of Illinois.*—The Debye theory of dielectric dispersion[1] for polar substances considers a material in an applied oscillating electric field whose frequency is much lower than any resonant frequencies of the molecules involved. Only the contribution to the electric polarization from molecular reorientations is considered to be damped, while that due to molecular distortions is not. As a consequence a plot of the imaginary *vs* the real part of the dielectric constant always results in a semicircle with center of the real axis. Experimental curves for many substances, however, deviate significantly from this semicircular locus.[2] It is shown in this paper that even a single additional damping term could account for most of the deviations. While it was not possible to make accurate calculations, estimates indicate that sufficient damping may exist in some of the molecular distortions.

[1] P. Debye, *Polar Molecules* (Chemical Catalog Company, Inc., 1929, or Dover Publications, New York, 1945), especially Chapter V.
[2] D. W. Davidson and R. H. Cole, J. Chem. Phys. **18**, 1417 (1950).

C10. Proton Magnetic Resonance Absorption and Water Content of Biological Materials.* T. M. SHAW, R. H. ELSKEN, AND C. H. KUNSMAN, *Western Regional Research Laboratory.*—Earlier work showed that magnetic absorption by protons may be used to measure water content over the range encountered in natural and dehydrated biological materials.[1] A linear relation was found between height of the proton absorption line and water content for typical vegetable tissues. Recent work in the low moisture region has shown departures from linearity for some materials, for example apple tissue and starch. A recording radiofrequency spectrometer was used, together with a 4600 gauss permanent magnet modulated by one gauss. The lines observed at 25°C for a number of proteins and carbohydrates containing 5 to 20 percent water are similar and consist of a line 0.7 gauss wide superimposed symmetrically on a line about 9 gauss wide.

* Investigations under Research and Marketing Act, Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration, U. S. Department of Agriculture.
[1] T. M. Shaw and R. H. Elsken, J. Chem. Phys. **18**, 1113 (1950).

C11. Biased Random Walks in Classical, Statistical, and Quantum Mechanics. GILBERT W. KING, *Arthur D. Little, Inc., and Research Laboratory of Electronics, Massachusetts Institute of Technology.*—The distribution of random walks biased in one direction is governed by a Fokker-Planck equation with a linear term in $\partial/\partial x$. For example, if the bias is $1\pm\Delta x/x$, the radial diffusion or Schroedinger's equation results. If the bias depends not on location, but history, no linear terms appear. The controlling equation is parabolic with a diffusion coefficient a function of the conditional probabilities of the Markoff process. If in one dimension the probability of "persistence of velocity" is α, the coefficient is $\alpha/1-\alpha$ times that for the isotropic case. The proof for walks in one or more dimensions depends on classifying particles by their history and finding the condition for solution of the simultaneous difference equations. Random configurations of polymer chains are under a bias, forbidding particles to re-enter a point they have just left, in a tetrahedral lattice. The distribution is strictly Gaussian, the coefficient being twice that for isotropic diffusion. Even steric effects, in particular excluded volume, leave the distribution Gaussian. The "diffusion" coefficient is a scalar function of the fraction of walks of N steps permitted when excluded volume is taken into account over a range n, provided, as $n, N\rightarrow\infty$, $n\ll N$.

C12. An Apparatus for Creep and Low Frequency Dynamic Studies on Polymers.* T. E. MORRISSON AND T. W. DEWITT, *Mellon Institute.*—An apparatus is described for the measurement in torsion of the low frequency (0.001 to 1 cycle per second) dynamic properties of solid polymers. Data may be obtained from the decay of free vibrations or from the response to a sinusoidal driving force. In the latter case the phase angle between stress and strain is obtained by a method similar to that used by Ké[1] in studying metals. A low frequency sine-wave generator is briefly described. Provision is also made for measurements of creep under constant torque. The treatment of data, and calibration and operating characteristics of the instrument, is discussed. The use of the instrument is illustrated with data on a sample of high molecular weight polyisobutylene.

* This work was supported by the Office of Rubber Reserve of the Reconstruction Finance Corporation, Washington, D. C.
[1] T'ing-Sui Ké and Marc Ross, Rev. Sci. Instr. **20**, 795 (1949).

C13. Measurements of Components of Stress Produced by Shearing Strain. E. H. FREI,* *Weizmann Institute of Science.*—If certain solutions of high polymers are sheared between concentric cylinders, they tend to climb up the inner cylinder. It has been assumed that shearing strain not only produces shearing stress but also tensions.[1] An instrument, similar to

a Couette viscosimeter, has been built in order to distinguish between the various components of stress. The pressure on the inner cylinder is measured while measuring simultaneously the shearing stress in the conventional way. Using cylinders with different diameters it is possible to evaluate the components of stress in simple cases. A latex solution is found to show strong components depending on the curvature of flow that probably result from a three-dimensional network of molecules.[2] This makes a resolution of the components with this instrument alone impossible. After the network is destroyed by continuous shear the behavior of the substance becomes simpler and the components can be evaluated.

* At present at Institute for Advanced Study, Princeton, New Jersey.
[1] K. Weissenberg, Nature **159**, 310 (1947); R. S. Rivlin, Proc. Roy. Soc. (London) **A193**, 260 (1948); T. G. Oldroyd, Proc. Roy. Soc. (London) **A200**, 523 (1950); M. Reiner, Quart. Appl. Math. **8**, 341 (1951).
[2] E. H. Frei and A. Katchalsky, (to be published).

FRIDAY MORNING AT 9:30

Sherman, Crystal Room

(A. W. LAWSON presiding)

Metals

D1. Solid-State Diffusion in Cylindrical Geometry. DAVID D. VAN HORN, *Knolls Atomic Power Laboratory.**—As a result of restrictions as to the size and type of diffusion specimen imposed by the natures of the systems to be studied, it has been necessary to develop techniques for the determination of diffusion constants from small cylindrical diffusion couples. Solutions of the diffusion equations in cylindrical geometry will be discussed, with particular regard for the analysis of sources of error in the measurements, and for comparisons with the solutions in linear geometry. Cylindrical specimens one-half inch long and of the order of 0.10 in. in diameter have been prepared by electroplating. A method has been developed for determining the diffusion penetration curves of such specimens by cathodic sputtering (to be presented in the succeeding paper). Experimental results will be shown for the diffusion of copper into nickel.

* The Knolls Atomic Power Laboratory is operated by the General Electric Company for the AEC. The work reported here was carried out under contract No. W-31-109 Eng-52.

D2. Cathodic Sputtering as a Sectioning Method in Diffusion Studies. THOMAS F. FISHER, *Knolls Atomic Power Laboratory.**—A cathodic sputtering method for the removal and collection of uniform surface layers from small cylinders is described. The system used consists of a cylindrical anode one inch in diameter and one inch long. The cathodes were cylinders of the order of 0.10-in. diameter and 0.5-in. long placed axially inside the hollow anode. Using krypton gas at 100 microns pressure and a potential of 2400 volts, the sputtering current was one milliampere. Under these conditions, one mil layers uniform to better than 0.05 mil could be removed from the cathode in approximately 24 hours. Pure metals, single phase alloys, and two phase alloys were studied. In all cases it was found that satisfactory uniform layers could be removed and that the composition of the collected metal agreed closely with that of the original alloys. This method is particularly suited for the study of diffusion in radioactive materials.

* The Knolls Atomic Power Laboratory is operated by the General Electric Company for the AEC. The work reported here was carried out under contract No. W-31-109 Eng-52.

D3. Experimental Evidence for the Vacancy Mechanism for Diffusion in Metals and Alloys.* FOSTER C. NIX AND FRANK E. JAUMOT, JR.,† *University of Pennsylvania.*—The diffusion of cobalt in cobalt-aluminum alloys of compositions near the 50–50 atomic percent composition was investigated in an attempt to test the vacancy mechanism of diffusion. These alloys have the property of containing a large number of vacancies in excess of the vacancies normally present in a lattice due to thermal excitations. The experimental technique used consisted essentially of computing the diffusion coefficients from the decrease in activity of radioactive Co^{60} due to the penetration of this isotope into the alloys. The value of the absorption coefficient of Co-Al alloys for the complex spectrum of Co^{60} required by the mathematical analysis was measured using powdered metal techniques. The results of diffusion of cobalt into cobalt-aluminum alloys of five different compositions, at temperatures of 1050°C, 1150°C, and 1250°C were obtained. The activation energy for the process was computed for each concentration. The data indicate that the diffusion coefficient has a minimum value at the ideal composition and rises sharply on the aluminum-rich side. Thus, the vacancy mechanism is indicated as the predominant mechanism in diffusion in substitutional alloys.

* This work was supported by the ONR.
† This paper is based on part of a thesis submitted by Frank E. Jaumot, Jr., in partial fulfillment of the requirements for the degree of Ph.D. at the University of Pennsylvania.

D4. X-Ray Study of Lattice Imperfections. P. H. MILLER, JR., *University of Pennsylvania.* In a spherical crystallite with the central scattering center missing from a simple cubic lattice shifts in the position of the diffraction maxima occur, as well as changes in the density and linear dimensions. The fractional changes are, respectively:

$$\frac{\Delta d}{d} = -8.4\frac{x}{M^3}$$

$$\frac{\Delta \rho}{\rho} = -\left(\frac{6}{\pi}+24x\right)\frac{1}{M^3}$$

$$\frac{\Delta l}{l} = +\frac{8x+2/\pi}{M^3},$$

where x is the fraction of an interatomic distance the nearest neighbors of the missing atom move outward, and M is the number of atoms along a diameter of the sphere. If x is positive, the crystallite becomes larger but the lattice constant apparently decreases. When these results are applied to the NiAl system one finds that the 46 atomic percent Ni alloy contains some Al atoms at Ni sites and a much smaller number of Ni vacancies than estimated by Bradley and Taylor.[1] Application of these equations to order disorder phenomena and Schottky and Frenkel defects will be discussed.

[1] A. J. Bradley and A. Taylor, Proc. Roy. Soc. (London) **159**, 56 (1937).

D5. An Electron Microscope and Diffraction study of the Aging of Evaporated Metal Films.* E. J. SCHEIBNER, *Illinois Institute of Technology.*—An electron diffraction study was made of the aging of thin metal films of aluminum, silver, and

gold on silicon monoxide substrates by transmission and on quartz crystals by reflection. The effect of aging, accelerated by heating, is determined for each film by an investigation of the resulting diffraction pattern and corresponding micrograph. It was found that a growth in grain size occurred in the films and that aluminum films developed a [111] fiber structure after aging. Successive stages in the aggregation of sllver and gold films are illustrated in their electron micrographs, while those of the aluminum films indicate their high resistance to aggregation. A modification of the diffraction specimen holder of the RCA type emu electron microscope permitted the insertion of an entire quartz crystal into the microscope column. With this adaptation it was possible to obtain reflection patterns from the films without destroying the crystals. A comparison between the properties of the metal films is made after examination of the results obtained from the diffraction patterns and micrographs.

* This research was supported by U. S. Army Contract under Signal Corps Project. The work was done at the State Engineering Experiment Station of Georgia Institute of Technology, Atlanta, Georgia.

D6. Tracer Method for Measurement of Evaporated Bi Film Thicknesses.* JOHN J. ANTAL AND A. H. WEBER, *Saint Louis University.*—A simple method for the measurement of very thin films prepared by evaporation in a vacuum through determination of the activity of an included tracer is given. A comparison of the activity of the film of unknown thickness to that of a standard of known mass gives the mass of the unknown film. The area of the unknown film is then measured with a planimeter and its thickness is computed. Because of the relative character of the measurements, the natural decay of the tracer is automatically accounted for. High accuracy in the range 1 to 100A, continuous calibration, and nondestruction of the specimen recommend this method. Bi^{210} was used successfully as a tracer in Bi films in the present experiments, with less than 4 percent error and a range in thickness of 1 to 300A. Two types of activity which occurred in the Bi^{210} standards are explained by a variation in the structure of the films determined by electron diffraction.

* Supported by a Research Corporation grant

D7. Temperature Dependence of Internal Friction at 44 kc.* W. B. NOWAK, *Massachusetts Institute of Technology.*—The internal friction of Al has been measured at 44 kc as a function of temperature for various amounts of cold work. The Al, 99.99+ percent pure, was in the form of resonant rods with an average grain diameter of 1.7 mm. Measurements were made from 300°K to 65°K and for compressional strains up to 1.35 percent. For the Al, and for annealed 99.5 percent Be (0.45 mm grain size), a broad low temperature maximum in the Q^{-1} *versus* temperature curve has been found in qualitative agreement with the literature. Upon cold working, the Q^{-1} of Al at 300°K increased and the magnitude of the low temperature peak relative to 300°K increased. Cold work also produced a temperature shift of the maximum from 143°K to 110°K. The existence of a minimum in the Q^{-1} of Al near 300°K is shown[2] and it is also shown that freshly annealed Al "ages," or anneals further, at 300°K. The apparatus will be described and a tentative explanation of the "aging" and of the low temperature peak will be put forth in terms of "pinned-down" dislocations and a possible relaxation effect.

* Sponsored by AEC. contract.
[1] P. G. Bordoni, Ricerca sci. (August, 1949), p. 851.
[2] J. Pittenger, Phys. Rev. **83**, 889 (1951).

D8. Effect of Plastic Deformation on Anelastic Properties of Alpha-Brass.* JOHN KAUFFMAN AND DAVID LAZARUS, *University of Illinois.*—Measurements have been made over a considerable temperature range of the effect of plastic deformation on the relaxation due to stress induced preferred orientation of Zn atoms[1] in 70–30 alpha-brass. Data were taken with large-grained polycrystalline wire specimens of 1 mm diameter, using a torsion pendulum. In a range of temperature above room temperature, plastically deformed specimens show a shorter relaxation time than annealed specimens. With increasing temperature, the effect disappears, and, in some cases, shows a reversal. The data are considered in terms of the vacancy mechanism for atomic diffusion. An excess number of vacancies is produced as a result of cold work and contributes to the diffusion process. These vacancies rapidly equilibrate at temperatures of the order of 220°C.

* Supported in part by the AEC.
[1] C. Zener, Phys. Rev. **71**, 34 (1947); T. S. Kê, J. Appl. Phys. **19**, 205 (1948).

D9. Temperature Dependence of the Resistivity of Deuteron Irradiated and Annealed Molybdenum.* BURTON RANDOLPH,† *Purdue University.*—The temperature dependence of the resistivity of molybdenum has been investigated for unannealed, annealed, and deuteron-irradiated samples between room temperature and 1.2°K. The resistivity at room temperature shows only a slight change upon annealing (a decrease of 3 percent) but somewhat more after bombardment (an increase of 4 percent). However, by extending the measurements to the helium range it has been found that the residual resistivity (constant from 12°K to 1.2°K) is twice as great in the unannealed sample than in the annealed, and three times greater in the bombarded sample. The specimens were cooled during bombardment with 10-Mev deuterons so that the actual temperature during bombardment was never higher than −100°C. By heating in hydrogen the irradiation effects can be healed out. The annealing process, as well as the behavior of the irradiated material as compared with cold-worked material, will be discussed.

* Supported by the AEC.
† To be introduced by K. Lark-Horovitz.

D10. Statistical Theory of Properties of Solid Solutions. R. SMOLUCHOWSKI, *Carnegie Institute of Technology.*—Properties of binary solid solutions are considered from the point of view of the fluctuation of local composition in the crystalline lattice. These variations influence the properties of the alloys by varying the corresponding local concentration of electrons. A simple general statistical method is given for calculating properties of random and ordered solid solutions. The basic group in a face-centered cubic lattice consists of an atom and its nearest neighbors. In a body-centered cubic atom and its nearest and second nearest neighbors which are only 15 percent further away. The theory is applied to saturation magnetization magnetostriction, thermoelectric power electrical resistance, and its temperature coefficient and other properties in various alloys. Satisfactory agreement with experiment is obtained.

D11. Thermal Conductivity of Metals. P. H. SIDLES AND G. C. DANIELSON, *Iowa State College.*—A new method of measuring thermal diffusivity and, hence, thermal conductivity of metals is suggested. Like the methods of King[1] and Starr,[2] this method uses a heat source, whose temperature varies sinusoidally, located at one end of an effectively infinite rod. Unlike these methods, only one period of the heat wave is required to eliminate the unknown coefficient determining the heat lost by radiation, since both velocity and amplitude decrement of the heat wave are measured. The new method is faster in taking data and simpler incomputation. The thermoelectric potentials from two thermojunctions are amplified and plotted on a Brown "Electronic" recorder, thus giving a permanent record of all necessary data for computing the thermal diffusivity. Results for different metals at room temperature and at elevated temperatures will be given.

[1] R. W. King, Phys. Rev. **6**, 437 (1915).
[2] C. Starr, Rev. Sci. Instr. **8**, 61 (1937).

D12. Optical Properties of Sodium Tungsten Bronze. G. C. DANIELSON AND E. CHIVERS, *Iowa State College.*—With the addition of sodium the insulator WO_3 acquires electrical properties corresponding to a metal with a concentration of free electrons in the conduction band equal to the concentration of sodium atoms.[1] These free electrons must also explain the change in color from blue to red to yellow with increasing sodium content. The color changes might be caused either by selective reflection, as suggested by the classical theory of Zener and successfully applied by Jaffe[2] to solutions of alkali metals in ammonia, or by internal photoelectric absorption, as suggested by Mott and Jones for copper and brass. Single crystals of the red and yellow "bronzes" have been grown large enough for us to measure the optical constants by polarimetric methods. For red or yellow light the optical constants have normal values as predicted by the classical theory of metals. For yellow crystals using blue light and for red crystals using green or blue light the absorption coefficient (nk) becomes anomalously large. This suggests that the color of these crystals is caused by internal photoelectric absorption rather than by selective reflection.

[1] Huibregtse, Barker, and Danielson, Phys. Rev. (to be published).
[2] H. Jaffe, Phys. Rev. **58**, 207 (1940).

D13. Design of Extensometer for Creep Studies.* R. PIZZARO† AND B. GOSSICK, *Purdue University.*—The extensometer incorporates automatic and remote operation for irradiation studies over a wide range of extensions (10 percent→10^{-3} percent). The creep specimen is mechanically coupled to a metal core within a mutual inductance bridge. The amount of deformation of the creep specimen determines the position of the core and thus the amount of bridge unbalance. The output of the bridge is electronically amplified and rectified. A recording milliammeter connected to the output of the rectifying stage records the creep rate. The tolerances of mutual inductance bridges being never perfect, a residual voltage always remains which is 90° out of phase with that produced by displacements of the core. By making a composite core of juxtaposed laminations of steel and copper, one can empirically obtain a core which produces output voltages in quadrature with those of a steel core. When two such bridges are connected together the null may be reduced to the order of the noise level of the amplifier to which the bridge system is connected. On our most sensitive scale, full-scale deflection corresponds to 1160A displacement of the metal core with a noise level corresponding to 40.6A. Creep curves with commercial copper wire will be presented.

* Supported by the AEC.
† To be introduced by K. Lark-Horovitz.

FRIDAY MORNING AT 9:30

Morrison, Mural Room

(A. O. NIER presiding)

Nuclear Instrumentation

E1. Resolution of Fast Neutron Energy Measurements using Proton Recoils from a Thin Radiator.* BEN R. GOSSICK,† *Purdue University.*—The general equation for analyzing counting data is

$$N(E)=\frac{8(g+1)M}{\pi g^2 S\zeta_1\zeta_2\zeta_3\zeta_4 ER(E)\sigma(E)},$$

where $N(E)$ represents the number of neutrons emitted per second per Mev from an isotropic point source. E is the energy of the protons, $R(E)$ the total range in the radiator material, $\sigma(E)$ the scattering cross section of hydrogen. ζ_1, ζ_2, ζ_3, and ζ_4 are fractional errors in energy due to uncertainties in (1) the beginning of the range, (2) the end of the range, (3) the angle of the incident neutron, and (4) the angle of the recoil proton respectively. s represents the hydrogen density of the radiator, n the counting rate, and g is given by Geiger's law $R(E)=KE^{g/2}$. By maximizing the counting rate at constant total error, the possible resolving power can be setimated. A well-designed spectrometer of this type will yield a total error of from 5 to 15 percent with source intensities in the commonly available range $3\cdot10^5<N(E)<10^7$.

* This work was done at Oak Ridge National Laboratory, Oak Ridge, Tennessee.
† To be introduced by K. Lark-Horovitz.

E2. A Crystal Spectrometer for Neutrons. L. B. BORST* AND V. L. SAILOR, *Brookhaven National Laboratory.*—A crystal spectrometer of the type described by Zinn[1] has been constructed for use with the Brookhaven reactor. A beryllium crystal[2] has been found to be exceptionally good as a neutron monochromator giving unusually strong Bragg reflections while having a double-crystal rocking curve of only 5 minutes width. The high intensity permits the use of planes of high Miller indices, which greatly enhances the resolution of the instrument. For example the $(12\bar{3}0)$ set of planes have a grating space of only 0.747 a.u., which give a first-order reflection for 1-ev neutrons at an angle of 11°. Using this set of planes preliminary cross-section curves have been obtained for In, Ir, Rh, and Au in the range from 1 ev to 10 ev. With a collimated beam of 10 minutes divergence the resolution is high enough to permit the observation of the natural widths of most resonances lying below 2.5 ev. At present more careful data are being taken on several resonances to obtain accurate values of the resonance integrals.

* Now at the University of Utah, Salt Lake City, Utah.
[1] W. H. Zinn, Phys. Rev. **71**, 752 (1947).
[2] Two excellent single crystals of beryllium were generously furnished by Professor A. R. Kaufman of the Division of Industrial Cooperation at MIT.

E3. Scintillation Neutron Detector.* WILLIAM BERNSTEIN AND A. W. SCHARDT, *Brookhaven National Laboratory.*—Lithium iodide crystals have been grown with up to 0.5 percent by weight of TlI as activator. The activated melt forms an opaque, brown, polycrystalline mass if cooled rapidly. Single crystals $\frac{1}{2}$-in. diameter and $\frac{3}{4}$-in. high have been grown with parts which are clear and white. Excess thallium was found at the crystal boundaries. The crystals were tested with thermal neutrons from a spectrometer. All activated crystals gave pulses well above noise whereas no scintillations were detected from unactivated crystals. A single line with a full width at half-maximum of 25 percent was obtained with under-activated crystals. The pulse height corresponded to that produced by 50–100 kev gamma-rays on Harshaw NaI-Tl. Crystals grown with an excess of activator showed one line equivalent to 100–170 kev on NaI-Tl. A continuous distribution of pulses was found above the line with a cutoff at 450-kev NaI-Tl equivalent. One crystal shows a second peak near the upper cutoff which is about 15 percent wide.

All pulses are stopped by interposing cadmium between the crystal and neutron source.

* Work performed under the auspices ot the AEC.

E4. Performance of 5819 Photomultipliers in Scintillation Spectrometers.* A. W. SCHARDT AND WILLIAM BERNSTEIN, *Brookhaven National Laboratory.*—Three dozen 5819 photomultipliers[1] have been tested for resolution with a $\frac{1}{2}$-in. cube NaI-Tl crystal permanently mounted in an aluminized reflector with a quartz window.[2] The full width at half-maximum of the photoline of 670 kev quanta varied between 9 and 16 percent with most tubes around 12 percent. For 22 kev the extremes are 35 to 60 percent with most tubes near 45 percent. An attempt was made to correlate these results with some of the photomultiplier characteristics such as quantum efficiency, gain, uniformity, noise, dynode voltages, and electron collection efficiency. If the voltage between photocathode and first dynode is above 200 volts no quantitative correlation could be found. However, tubes with high cathode sensitivity have in general a better resolution.

* Work performed under the auspices of the AEC.
[1] We are indebted to R. W. Engstrom of RCA, Lancaster, for the loan of some selected tubes.
[2] A. W. Schardt and W. Bernstein, "Resolution of scintillation spectrometer," Rev. Sci. Instr. (to be published).

E5. Monitor for Natural Radioactivity in the Atmosphere.* M. H. WILKENING, *New Mexico Institute of Mining and Technology.*—A monitor for studying the decay products of radon and thoron found in the atmosphere is described. A point-to-plane type of electrostatic precipitator is used to collect samples of particulate matter from the atmosphere and deposit them on a moving metallic tape. The activity associated with the collected material can be measured either with a scintillation counter for detection of the alpha-activity or with an end-window Geiger counter for detection of the beta-activity. A count rate meter and strip-chart recorder are used to give a permanent register of the activity. A kymograph type of synchronous motor and set of reduction gears is used as a driving mechanism for the collecting tape. By varying the speed, the monitor's response can be set to emphasize either the short-lived (3.05 min) RaA, the radon products RaA through RaC″ (effective half-life about 40 min), or the long-lived, low level ThB (10.6 hr) activity. Under normal monitoring conditions which favor the radon products, counting rates varying from about 50 to 200 counts per minute above background are obtained. The instrument is planned for use in correlating atmospheric radioactivity with fluctuating aerosol concentrations and varying meteorological conditions.

* Research supported by funds from the ONR.

E6. A Combination Cloud-Ion Chamber using Cylindrical Geometry.* FIELDING BROWN, R. R. RAU, AND GEORGE T. REYNOLDS, *Princeton University.*—Following general principles previously reported,[1,2] a cloud-ion chamber using cylindrical geometry has been constructed and is in operation. The chamber contains three concentric electrodes: $\frac{1}{4}$-in. diameter steel, $3\frac{5}{32}$-in. o.d. by $\frac{3}{32}$-in. thick glass, and $8\frac{1}{4}$-in. o.d. by $\frac{1}{4}$-in. thick glass. The outer glass electrodes are coated with a transparent and electrically conducting coating to permit cloud-chamber illumination and also make ion chamber action possible. The outermost electrode serves as the chamber wall and the intermediate cylinder (collecting electrode) is at +1400 volts. This permits electron collection throughout the entire chamber volume. Thus heavily ionizing events, such as stars, which are produced in the approximately 5 liters of chamber gas, are photographed and the size and shape of associated ion chamber pulses can be recorded. Typical events will be shown.

* Supported by the joint program of the AEC and ONR.
[1] M. J. Cohen, Phys. Rev. **75**, 1329 (1949).
[2] Lewis, Brown, Seevers, and Hones, Rev. Sci. Instr. **22**, 259 (1951).

E7. Scattering of Light from Small Drops. RICHARD L. LANDER AND C. E. NIELSEN, *Ohio State University.*—Small drops were produced in a continuous cloud chamber, and the angular distribution of light scattered from them was studied over the range of angles from 28° to 147°. The detecting system was a phototube circuit and galvanometer. Values of intensity obtained with no drops present, but with other conditions unchanged, were subtracted from the values observed with drops in the chamber in order to obtain the intensity of light scattered from the drops alone. Data obtained by photographic methods exist for the range 20° to 100°.[1] The present results agree well with these data, but the observed intensities at angles between 100° and 147° are considerably greater than had been speculated. The ratio of the intensity at 140° to that at 40° is about 5:7 for drops of radius 1.4×10^{-3} cm. The speculated ratio is about 1:15. For drops of radius 4.8×10^{-4} cm the ratio is 1:8, indicating that the angular distribution depends strongly upon the drop size.

[1] J. G. Wilson, *The Principles of Cloud Chamber Technique* (Cambridge University Press, London, 1951).

E8. Special Techniques For Processing Thick Nuclear Emulsions. BERTRAM STILLER, MAURICE M. SHAPIRO, AND FRANCIS W. O'DELL, *Naval Research Laboratory.*—A modified procedure for uniform development of 400μ ultrasensitive emulsions by the temperature-cycling method[1] is described. A favorable ratio of minimum grain density to background is obtained by warm, "dry" development with amidol for $\approx$20 min at 23°C. Dry development also reduces the incidence of surface deposits of colloidal Ag. A pre-wiping technique further inhibits these deposits while avoiding the risk of distortion from wiping the wet swollen emulsion. We have confirmed[1] that swelling is markedly reduced by fixing and washing at 5°C. Clearing time for 400μ emulsions is thereby extended <30 percent. The tendency of thick emulsions, once dried, to strip from their base is prevented by (a) immersion in a plasticizing solution, (b) application of a protective coating, and (c) storage and use in a constant-humidity environment. "Eradication" and resensitization of 400μ Ilford G5 emulsions is achieved by a 7-day exposure to a moisture-saturated atmosphere at 35°C, followed by drying.[2] A stack of emulsions without glass support provides a large sensitive volume in which tracks can be readily followed from one layer to the next.[3] The lateral swelling ($\approx$25 percent) which has heretofore discouraged the use of such emulsions is prevented by a special method of mounting and processing them, based on a suggestion by C. Waller of Ilford, Ltd.

[1] Dilworth, Occhialini, and Vermaesen, Bull. centre phys. nucleaire Bruxelles No. 13a; Bonetti *et al.*, *ibid.*, No. 13b.
[2] M. Wiener and H. Yagoda, Rev. Sci. Instr. **21**, 39 (1950).
[3] P. Demers, Phys. Rev. **78**, 320 (1950).

E9. A Combination Crossed-Field and Time-of-Flight Mass Spectrometer. J. A. HIPPLE AND H. SOMMER, *National Bureau of Standards.*—A crossed-field mass spectrometer in which the ions take a trochoidal path having multiple cycles has been modified to permit accurate timing with a high frequency voltage for a time-of-flight of the ions of n complete cycles. The operation is based on the fact that the time for one complete cycle is given by the cyclotron frequency condition. The entering ions pass between two parallel wires placed on the focal plane where a sinusoidal voltage deflects the ions in the direction of the magnetic field causing them to miss the final exit slit unless they pass between the wires when the rf voltage is near zero. After n complete cycles those ions which were not deflected by the first pair of electrodes pass through a similar pair of electrodes connected to the same source of rf voltage and will not be deflected if the frequency is a multiple of half the cyclotron resonant frequency. The ions not deflected by the two pairs of electrodes are able to pass through a final slit to the ion collector, and the current is measured with a

dc amplifier or multiplier. The advantages over other schemes based on the cyclotron frequency condition will be discussed.

E10. The University of Kansas Van de Graaff Generator.* L. W. SEAGONDOLLAR, R. K. SMITH, W. R. ALEXANDER, AND J. W. TEENER.—This generator was designed to fit into an ordinary laboratory room 50 ft×25 ft×10 ft so as to leave maximum space for target and detecting assemblies. It follows the Herb design and is contained in a steel pressure tank 16 feet long and 6 feet in diameter. The steel tank is mounted on concrete piers. The removable head of the tank is mounted on a heavy rolling cart and all generator components are mounted on the head. The generator is rolled out of the tank for maintenance or repair. The seven-foot accelerator tube has six-inch i.d. electrode spinnings. Electron loading makes the present voltage limit two million volts. Stable operation occurs up to and including the $Li^7(p, n)$ threshold. A Zinn type ion source is used. Stability is obtained by corona current control using a 25-degree electrostatic analyzer on the mass-2 beam. Further comment will be made on the design of the generator and operational characteristics will be discussed.

* Supported in part by the ONR.

E11. The Oak Ridge 86-in. Cyclotron. ROBERT S. LIVINGSTON, *Oak Ridge National Laboratory.*—During the spring of 1951 an 86-in. fixed frequency proton cyclotron has been placed in successful operation. The energy reached by the protons exceeds 20 Mev as determined by the frequency and the geometry, and also by the $C^{12}(p, pn)C^{11}$ reaction. The protons at terminal energy are more than 2 percent relativistic. This has been made possible by the use of optimized magnetic shimming and increased radiofrequency voltage between the dees. Internal currents of hundreds of microamperes above 20 Mev have been observed. Beam measurements have been made by probes equipped with electron traps and by calorimetry techniques. Several unique features of the mechanical design of the cyclotron are (1) horizontal magnetic field with the median plane vertical; (2) insulated, negatively-biased dees to provide satisfactory operation with a self-excited, grounded-grid oscillator; (3) heavily water-cooled dees suspended vertically; (4) demountable dee-assembyl with provision for rapid replacement in case of failure or need for revised experimental facilities; (5) suppression of radioactivity induced in dees by use of appropriate lining; (6) high pumping speed system with resulting fast pump-down time; (7) targets which will withstand 10 kw of beam without deterioration; (8) bayonet-type vacuum seal for rapid removal of target heads; (9) ion source removable through a vacuum lock.

E12. Operating Current and Energy of the M.I.T. Linear Electron Accelerators.* M. LABITT, R. J. DEBS, I. HALPERN, AND P. T. DEMOS, *Massachusetts Institute of Technology.*—The M.I.T. Linear accelerator is one of the standing wave type.[1] It is 21 feet long and is powered by tunable magnetrons which are operated in pulses two microseconds long at 120 cps. The accelerator is currently being used at a maximum energy of about 17 Mev with average currents of several microamperes. The energy spread of the electrons within a single pulse is from 2 to 4 Mev, and there is an additional energy "jitter" of about $\frac{1}{2}$ Mev from pulse to pulse. The accelerator beam is probably less than $\frac{1}{16}$ in. in diameter, but moves about within an area of diameter $\frac{3}{8}$ in. in successive pulses. Although the adjustment of the accelerator controls for maximum energy and best beam definition is fairly critical, it has been found that, once adjusted, the properties of the accelerator beam will remain unchanged for several hours at a time. The electron beam leaves the accelerator through a thin aluminum window, emerging into a well-shielded target room. The beam has been used both directly and to produce x-rays. So far, the main use of the accelerator has been for photonuclear experiments.

* This work was assisted by the joint program of the ONR and AEC and is described in more detail in the M.I.T.-L.N.S.E. Technical Report No. 50 by P. T. Demos.

[1] See J. C. Slater, Revs. Modern Phys. **20**, 473 (1948).

FRIDAY AFTERNOON AT 2:00

Sherman, West Room

(J. H. VAN VLECK presiding)

Magnetism; Low Temperatures

F1. Ferromagnetic Domain Structure of Single Crystals and Bicrystals of Nickel.* URSULA M. MARTIUS, K. V. GOW, AND BRUCE CHALMERS, *University of Toronto.*—Single crystals and bicrystals of nickel, with predetermined orientation, have been grown by the methods of Chalmers and Gow. The following range of orientation was studied: Crystals which contained two ⟨111⟩ directions in the plane of the surface, and small deviations from this orientation; crystal with a single ⟨111⟩ direction in the plane of the surface and specimens with a (100) plane as the crystal surface, hence containing no direction of easy magnetization in the plane of the surface. The colloid technique was used to study the domain structure on the carefully electropolished crystal surfaces. The general features of the domain structures are in agreement with the predictions of the theory. The patterns on nickel are very sensitive to small differences in crystallographic orientation. Two effects have been observed in the proximity of small angle crystal boundaries. Changes in domain spacing and new substructures can result directly from the small differences in crystal orientation; also, curvature of the Bloch wall has been found in many patterns. The curvature is attributed to lattice strains associated with the crystal boundaries.

* Martius, Gow, and Chalmers, Phys. Rev. **82**, 106 (1951).

F2. Effect of Stress on the Curvature of Domain Boundaries. H. J. WILLIAMS AND R. M. BOZORTH, *Bell Telephone Laboratories.*—Most domain boundaries are plane surfaces, which have been observed as straight lines on magnetic domain patterns. Some curvature has been noted,[1] especially in nickel, which has a high magnetostriction and a moderately low crystal anisotropy. Photographs of domain patterns now show large curvature near regions that have been plastically deformed. Plastic deformation of other materials, including a silicon-iron alloy, causes marked changes in their domain patterns, and a variety of these will be shown. The attempt has been made to study experimentally the relation between stress and curvature in material having a simple stress distribution. Often the patterns are quite complex.

[1] H. J. Williams and J. G. Walker, Phys. Rev. **83**, 634 (1951).

F3. Strain Induced Curvature of Bloch Walls in Silicon Iron. L. J. DIJKSTRA AND U. MARTIUS, *Ontario Research Foundation.*—In a study of the ferromagnetic domain patterns in a large-grained silicon iron, special attention has been directed to the effect of stress especially in the vicinity of grain boundaries. It has been observed that increasing stress causes a sequence of changes in the pattern, commencing with a reorientation of the domains and subsequent splitting up into narrower domains by a process which appears to nucleate at the boundaries. Considerable local curvature of the domain walls is inherent in this splitting process. On the other hand, marked curvature of the Bloch walls can also be observed in regions where plastic deformation has caused the lattice to become curved; in such cases, curvature of the lattice has been confirmed by x-ray diffraction.

F4. Magnetically Induced Ultrasonic Velocity Changes in Polycrystalline Nickel.* S. J. JOHNSON, *Andersen Laboratories,* AND T. F. ROGERS,** *Cambridge Research Center.*—Measurements on the changes of ultrasonic velocity in pure polycrystalline nickel rods induced by the application of magnetic fields[1] have been continued. Large diameter rods are used in order to provide high D/λ ratios in the 1- to 10-megacycle region. Velocity changes have been noted for both compressional and shear waves with magnetic fields either along or transverse to the rod axis. Such changes, attributable to the ΔE effect,[1,2] show a marked decrease with increasing frequency; representative compressional saturation values of 3 percent and 0.8 percent are obtained at 1 and 5 megacycles, respectively. Comparison with published data for single nickel crystals[2,3] shows general agreement as to the nature and magnitude of the effects noted, but the polycrystalline saturation values are appreciably smaller.

* Supported by the Air Force Cambridge Research Center.
** Now at the Massachusetts Institute of Technology.
[1] T. F. Rogers and S. J. Johnson, J. App. Phys. **21**, 1061 (1950).
[2] Mason, McSkimin, and Bozorth, Phys. Rev. **83**, 220(A) (1951).
[3] W. P. Mason, Phys. Rev. **82**, 715 (1951).

F5. Approximate Treatment of Order-Disorder Transitions in the Triangular Ising Lattice. L. D. FOSDICK AND H. M. JAMES, *Purdue University.*—The approximation method previously applied to the treatment of the order-disorder transition in the square Ising array in two dimensions[1] has been applied to the triangular lattice, with similar results. Attention is fixed on a central dipole surrounded by a hexagon of dipoles. Two order parameters represent the tendency of coupling to other dipoles to produce short-range and long-range order of the dipoles under consideration; two consistency relations serve to fix these parameters as functions of the temperature and coupling energy. The Curie temperature indicated by this method is about 10 percent higher than the known exact value, being close to the value obtained by the quite different method of Kikuchi.[2] Our method indicates a finite jump in the specific heat at the Curie point, but a considerably larger one than that given by Kikuchi's method; it therefore appears that the present method permits more accurate description of the system near the Curie point.

[1] H. M. James and L. D. Fosdick, Phys. Rev. **81**, 312(A) (1951). Erratum: The method gives a finite discontinuity in the specific heat of a square lattice, not an infinite one as reported there.
[2] R. Kikuchi, Phys. Rev. **81**, 988 (1951).

F6. Statistics of the Three-Dimensional Ferromagnet. B. MARTIN,* D. TER HAAR,† and V. A. JOHNSON, *Purdue University.*—The variational method of Kramers and Wannier has been applied to the three-dimensional ferromagnet.[1] A cubic Ising model with interaction of only nearest neighbors has been used. Denote by J the interaction energy corresponding to the difference between the state in which neighboring spins are parallel and that in which they are antiparallel. The partition function is

$$f=\Sigma_{\mu=\pm 1}\exp(K\,\Sigma_{\mu\mu'}),$$

where $K=J/2kT$ and the summation is extended over all spins in the crystal. The partition function is approximated through two reductions, each of which leads to an eigenvalue problem which is treated by the Ritz method. The configurational energy and specific heat are calculated from the appropriate derivatives of the partition function. A series solution for f was derived earlier. Now a numerical solution has been obtained for small k, and corresponding numerical values of specific heat and energy have been calculated. The numerical and series values agree well, with the difference increasing with K.

* Now at Owen-Illinois Glass Company, Toledo, Ohio.
† Now at University of St. Andrews, Scotland.
[1] See D. ter Haar and B. Martin, Phys. Rev. **77**, 721(L) (1950) for the series solution and additional references.

F7. An Approximate Quantum Theory of the Antiferromagnetic Ground State. P. W. ANDERSON, *Bell Telephone Laboratories.*—Klein and Smith[1] have shown that a careful treatment of the zero-point energy in the Heller-Kramers[2] semiclassical theory of ferromagnetic spin waves leads one to quite exact results for various properties, particularly the energy, of the ferromagnetic ground state as well as of the low excited states. This is the result of the fact that the Kramers-Heller treatment is basically a purely quantum-mechanical approximation valid to order $1/S$. (S is the spin quantum number of the atoms in the ferromagnet.) A similar treatment of the antiferromagnet, for which the ground state is not known, has been carried out, based on Hulthén's[3] spin-wave treatment of the antiferromagnetic lattice. Results are obtained valid to order $1/S$ for the energy and for the long-range order in the ground state of the simple cubic and plane lattices. For the linear chain the method shows that the zero-point energy of the spin waves is alone adequate to destroy long-range order, a result which agrees with the exact treatment of Hulthén.[4] Nonetheless, a surprisingly close estimate of the energy is obtained in this case.

[1] Klein and Smith, Phys. Rev. **80**, 1111 (1950).
[2] Heller and Kramers, Proc. Amst. Acad. Sci. **37**, 378 (1934).
[3] L. Hulthén ,Proc. Amst. Acad. Sci. **39**, 190 (1936).
[4] L. Hulthén ,Ark. für Mat., Astron. o. Fys. **26a**, 11 (1938). See also H. Bethe, Z. Physik **71**, 205 (1931).

F8. On Generalizations of the Weiss Molecular Field Theory of Antiferromagnetism.* J. SAMUEL SMART, *U. S. Naval Ordnance Laboratory.*—The usual Weiss molecular field treatment of ferromagnetism and antiferromagnetism considers only interactions between nearest neighbors. Recent work of Néel[1] and Anderson[2] has indicated the importance of considering second nearest neighbor interactions as well. If both interactions are included and are allowed to be either ferromagnetic or antiferromagnetic, there are four possibilities as indicated in Table I. The calculations of Néel and Anderson

TABLE I.

	I	II	III	IV
Nearest neighbor	*f*	*a*	*a*	*f*
Second nearest neighbor	*f*	*a*	*f*	*a*

(Case II) have been extended to Cases III and IV for b.c.c. and f.c.c. lattices. For Case III, the material is antiferromagnetic with ordering of the first kind for all values of γ_2/γ_1, where γ_1 and γ_2 are the molecular field coefficients for first and second nearest neighbor interactions, respectively. For Case IV, the material is ferromagnetic for small γ_2/γ_1 and antiferromagnetic with ordering of the second kind for large γ_2/γ_1. The relation of these results to the experimental data on antiferromagnetic compounds will be discussed.

* Supported in part by ONR.
[1] L. Néel, Ann. phys. **3**, 137 (1948).
[2] P. Anderson, Phys. Rev. **79**, 705 (1951).

F9. The Magnetic Susceptibility of Zinc at Liquid Nitrogen Temperatures. J. W. McCLURE,* *Northwestern University.*—Measurements were made of the difference between the susceptibilities parallel and perpendicular to the hexagonal axis of zinc, employing a torsion method. The specimen was a single crystal of New Jersey Superpure zinc, weighing about 0.7 gram. The susceptibility parallel to the hexagonal axis was found to be field dependent in the region investigated, 54°K to 85°K and 2.7 to 9.7 kilogauss. The order of magnitude of the variations was 0.01×10^{-6}. While definite maxima and minima were observed, the range of measurements was not large enough to determine if the susceptibility as a function of field strength oscillates as in the de Haas-van Alphen effect.[1,2] Measurements were also made on a zinc specimen containing 0.016 atomic percent copper. These results differed from those for pure zinc by order of experimental error, about 0.001×10^{-6}.

* Now at the University of Chicago, Chicago, Illinois.
[1] J. A. Marcus, Phys. Rev. **76**, 413, 621 (1949).
[2] S. Sydoriak and J. Robinson, Phys. Rev. **75**, 118 (1949).

F10. Specific Heats of Several Metals and Semiconductors between 1.8 and 4.2°K.* I. ESTERMANN AND S. A. FRIEDBERG,** *Carnegie Institute of Technology.*—Specific heats of very pure samples of magnesium, titanium, zirconium, and germanium and an impure sample of germanium† have been measured between 1.8 and 4.2°K. In each case, C_v can be resolved into an electronic contribution, γT, and a lattice contribution, $464.5(T/\theta)^3$. From the γ-values, the density of states at the Fermi level, $N(E_0)/n_a$, and the effective mass ratio, m^*/m, of the conduction electrons have been calculated. These quantities and the values of γ and θ are given in Table I.

TABLE I.

Sample	θ	$\gamma\times10^4$	$N(E_0)/n_a$ levels/atom/ev	m^*/m
Mg	342	3.25	0.289	1.33
Ti	290	8.29	0.736	3.26
Zr	265	6.92	0.615	2.24
Cr	400	3.74	0.332	2.88
Ge (pure)	278	0.00	···	···
Ge (impure)	286	1.29	0.115	7.39

* Assisted by the ONR.
** Westinghouse Graduate Fellow in Physics during the course of much of this work.
† A p-type sample, degenerate at these temperatures and containing 3.7×10^{19} holes/cm³.

F11. Some Observations on the Superconductive Transition in Pure Metals.* W. F. LOVE, *University of Pennsylvania.*—Mendelssohn and MacDonald[1] have reported that with properly prepared samples the superconductive transition in a longitudinal magnetic field is continuous, reversible, and spread over a considerable range of magnetic field strengths. Several specimens of pure Sn, In, and Tl have been prepared in 50μ bore capillaries, using a variety of methods of attaching current and potential leads. In all cases, the transition is continuous in increasing field strengths. In decreasing fields, considerable hysteresis develops and the transition to the normal state occurs in a single discontinuous step in most cases, and in fields considerably below that which resistance first began to appear in increasing fields. One specimen of indium returned to the normal state in several discrete steps, probably due to the existence of several crystallites, since another specimen prepared in the same manner showed a single drop. These results support the earlier measurements of de Haas and Voogd.[2]

* Supported by the AEC.
[1] Mendelssohn and MacDonald, Proc. Roy. Soc. (London) **A200**, 66 (1949).
[2] De Haas and Voogd, Leid. Comm., No. 191d.

F12. Meissner Effect in Alloys of In-Tl and Sn-Bi.* E. CALLEN, W. F. LOVE, AND F. C. NIX, *University of Pennsylvania.*—The Meissner effect in single crystal spherical specimens of In-Tl alloys has been measured by the magnetic method of Shoenberg.[1] For concentrations up to 10 atmos percent Tl the frozen in flux is small and the magnetic properties like those of pure superconducting metals, as has been previously reported.[2] For higher concentrations of Tl increasing deviations are observed, especially as regards the breadth of the magnetic transition. The frozen in flux shows a maximum at compositions in the region of the transformation (cubic to tetragonal) occuring in this system. In the intermediate state, the diamagnetic moment of specimens of high Tl content is very sensitive to the small mechanical disturbances caused by the measuring technique. In increasing fields, the moment decreases with successive displacements of the sample, while in decreasing fields, it increases. In both cases, a final equilibrium value is attained after sufficient mechanical agitation. A considerable amount of the frozen in flux can be destroyed in this manner. Preliminary studies on a Sn plus 5 atmos percent Bi alloy show that the frozen in flux can be reduced to 20 percent by annealing a sufficiently long time.

* Supported by the AEC.
[1] Shoenberg, Proc. Roy. Soc. (London) **A175**, 49 (1950).
[2] J. W. Stout and L. Guttman, Phys. Rev. **79**, 396 (1950).

F13. The Melting Curve of He³. D. W. OSBORNE, B. M. ABRAHAM, AND B. WEINSTOCK, *Argonne National Laboratory.*—Measurements of the melting pressure of He³ have been made by the blocked capillary technique from 1.51°K to 0.16°K. The data between 1.09°K and 0.16°K were obtained by surrounding the cupro-nickel capillary with iron ammonium alum, which was cooled by adiabatic demagnetization. In order to facilitate thermal contact between the small tube and the salt, copper vanes were soldered to the capillary, and the salt chamber was filled with He⁴ to a pressure of 1 atmos at 77°K. From 1.51°K to 0.5°K the melting pressure follows the equation $P=26.8+13.1T^2$ atmos, but below 0.5°K the experimentally determined pressure rapidly approaches a constant value of 29.3 atmos. Further experiments are needed to determine whether the horizontal portion of the observed melting curve is to be attributed to poor thermal contact between the capillary and the salt below 0.5°K or to a transition in the liquid near 0.5°K. Regardless of this question it seems clear that the liquid is the stable condensed phase of He³ at 0°K.

FRIDAY AFTERNOON AT 2:00
Sherman, Crystal Room
(J. R. PLATT presiding)

Spectroscopy—Radio Frequencies to X-Rays

G1. On a Multiple Scattering Theory of the Grating and the Wood Anomalies.* VIC TWERSKY, *Mathematics Research Group, New York University.*—The wave scattered by a grating of cylinders (or bosses on a perfectly conducting or rigid plane) is obtained as an infinite sum of "orders of scattering." The first order is the usual single scattering approximation,

while the higher orders include sums of products of single cylinder scattering coefficients and Schlömilch series involving Hankel functions of spacing. For $a \ll \lambda/2\pi \ll b, r$ (radius-a, spacing-b, distance-r) all orders are summed explicitly on neglecting end effects and certain "resonance wavelengths" discovered. These correspond to optimal simultaneous fulfilment of the physical conditions that the magnitudes of all orders be maxima and that either successive orders be in phase to reinforce, or out of phase to partially annul the first. These "maximal effects" should appear as bright and dark bands (overlaying the usual continuous spectra observed with broad-band radiation) at wavelengths somewhat longer than those having principal maxima in the grating's plane (Rayleigh's values), with intensities ranging from say 25–0.28 times the single scattered values, widths roughly proportional to λ^2, and character determined by material, polarization, and angle of incidence. These are not the usual ghosts that haunt the grating but are rather close kin of the skeletons in its closet discovered by Wood in 1902.

* Research supported in part by the Geophysical Research Directorate of the Air Force.

G2. The Arc Spectrum of Germanium. KENNETH L. ANDREW AND K. W. MEISSNER, *Purdue University.*—Despite earlier investigations of the germanium arc spectrum by Gartlein,[1] Rao,[2] and Kiess[3] many combinations and many predicted terms are still missing. A reinvestigation of the spectrum was, therefore, justified. A quartz arc lamp employing pure germanium electrodes covered with pure germanium dioxide was developed and yielded about 150 new lines between 10 460A and 4735A. This source produces very sharp lines. Wavelength measurements with a 30-foot concave grating and a Perot-Fabry interferometer resulted in the following contributions to the term analysis: (1) Kiess' terms arising from the $4s^24p5p$-configuration were verified and the missing $5p\,^1P_1$-term was found. (2) Three terms attributed by Kiess to the $4s^24p6p$-configuration have been confirmed and six of the missing seven terms of this configuration established. (3) Many of the new lines were identified as combinations between the even $5p$-terms and known odd terms found by Gartlein and Rao. (4) New odd and even terms were found.

[1] C. W. Gartlein, Phys. Rev. **31**, 782 (1928).
[2] K. R. Rao, Proc. Roy. Soc. (London) **A124**, 465 (1929).
[3] C. C. Kiess, J. Research Natl. Bur. Standards **24**, 1, RP 1266 (1940).

G3. Long Forbidden $s-ns$ Series in RbI. J. E. MACK, *University of Wisconsin.*—The forbidden lines previously interpreted[1,2] as $s-(n-3)f$ must be reinterpreted as $s-ns$. The high f-terms cannot be resolved from their neighbors with higher l-values. Thus, there occur in a 28-meter absorption path in rubidium the absorption lines (attributable to fields from neighboring atoms) $6s^2S_{\frac{1}{2}}-ns^2S_{\frac{1}{2}}$, where n runs from 32 to 52 or possibly 53.

[1] H. R. Kratz and J. E. Mack, Phys. Rev. **76**, 173(A) (1949).
[2] J. E. Mack, Phys. Rev. **77**, 745(A) (1950).

G4. K-Excitation Potentials of the Elements. G. L. ROGOSA, *Florida State University.*—Tables of the K-excitation potentials or the K-absorption limits of the elements are easily available, but practically all of these tables suffer from two defects: (1) a confusion of the relationship of the Siegbahn x-unit to the angstrom; (2) the use of old inaccurate data. The values of the excitation potentials are particularly important in the calibration of highly stabilized, high voltage x-ray power supplies and in the precise measurement of gamma-ray energies by internal conversion experiments, especially with the improvements in the magnetic field measurements.[1] The preparation of a table of excitation potentials in absolute volts is proceeding by careful investigation of the available literature and the use of the necessary fundamental constants as given by DuMond.[2] Particular use is made of the tables by Cauchois and Hulubei.[3] The criteria for the selection of particular values will be discussed and copies of the tables will be made available.

[1] Walter I. Brown, Phys. Rev. **83**, 271 (1951).
[2] J. W. M. DuMond and E. R. Cohen, Phys. Rev. **82**, 555 (1951).
[3] Y. Cauchois and H. Hulubei, *Longuers D'Onde des Émissions X et des Discontinuités D'Absorption X.*

G5. The Nuclear Spin of Cl^{36} from the Microwave Spectrum of $C^{12}H_3Cl^{36}$. D. A. GILBERT, *State University of Iowa.*—The early work of Wu and Feldman[1] on the β-spectrum of $Cl^{36}\rightarrow A^{36}$ was interpreted to require a spin change $\Delta I=3$ and hence the spin of Cl^{36} to be 3; however, in a more recent paper[2] Wu and Feldman point out that a unique value of ΔI cannot be obtained from this β-spectrum. The microwave spectrum of $Cl^{36}CN$, as measured by Townes and Aamodt,[3] would require spin 2. The present work shows clearly that the spin is 2. In this experiment a study was made of the $J=0\rightarrow 1$ rotational transitions of $C^{12}H_3Cl^{36}$. The observed hyperfine pattern is shown to fit best with the theoretical pattern for $I=2$. The magnitude of the frequency separations gives the value -15.6 ± 0.6 mc for the quadrupole coupling constant, eqQ, and $-0.0164\pm 0.0008\times 10^{-24}$ cm^2 for the nuclear electric quadrupole moment, Q. This work was supported by the ONR.

[1] C. S. Wu and L. Feldman, Phys. Rev. **76**, 693 (1949).
[2] C. S. Wu and L. Feldman, Phys. Rev. **82**, 457 (1951).
[3] C. H. Townes and L. C. Aamodt, Phys. Rev. **76**, 691 (1949).

G6. The Nuclear Moment and Hyperfine Structure Anomaly of K^{40}.* JOSEPH T. EISINGER AND BENJAMIN BEDERSON, *Massachusetts Institute of Technology.**—An atomic beam method was used to measure the following quantities: $g_I(K^{40})/g_I(K^{39})=-1.2434\pm 0.0003$, $\mu_I(K^{40})=-1.2965\pm 0.0004$ nm, $\Delta\nu(K^{40})=1285.790\pm 0.007$ Mc/sec. A mass spectrometer was used to separate the K beam into its isotopes, K^{40} being detected by an electron multiplier. The transitions were observed at high fields, the line widths being 3 kc/sec at about 150 Mc/sec. According to Bohr and Weisskopf[1] the hfs, calculated on a point dipole assumption, must be corrected by a factor $1+\epsilon$ where ϵ depends on the structure of the nucleus. The present experimental data yield $\Delta=\epsilon(K^{39})-\epsilon(K^{40})=[\Delta\nu(K^{39})/\Delta\nu(K^{40})][g_I(K^{40})/g_I(K^{39})](9/4)-1=(0.46\pm 0.03)$ percent. Different nuclear models for K^{40} were used to obtain theoretical values for Δ. Satisfactory agreement can most readily be obtained when the asymmetrical nuclear model proposed by Bohr[2] as a refinement of the Bohr-Weisskopf theory is used.[3]

* This work was supported in part by the Signal Corps, the Air Materiel Command, and the ONR.
[1] A. Bohr and V. F. Weisskopf, Phys. Rev. **77**, 94 (1950).
[2] Aage Bohr, Phys. Rev. **81**, 331 (1951).
[3] Aage Bohr, private communication.

G7. Quadrupole Moment of the Electron Distribution in the Hydrogen Molecule.* N. J. HARRICK, R. G. BARNES, AND P. J. BRAY, *Harvard University.*—Measurements on the Harvard molecular beam apparatus, making use of a long homogeneous magnet and the Ramsey separated rf technique, have been made on transitions $m_I=0$, $m_J=-1\rightarrow 0$, and $m_I=0$, $m_J=0\rightarrow +1$ in H_2. From these measurements the rotational magnetic moment and dependence of the diamagnetic susceptibility on the orientation of the molecules' rotational angular momentum have been calculated to be $\mu_R=0.88287\ 0.00008$ nm and $\xi_{\pm 1}-\xi_0=-(3.86\pm 0.20)\times 10^{-31}$. From the former, the contribution of the high frequency terms to the susceptibility per molecule of H_2 is determined to be $\xi_{HF}=1.5115\pm 0.0002\times 10^{-31}$. The quadrupole moment relative to the internuclear axis is

$$Q_e=-20(mc^2/e^2)[(\xi_{\pm 1}-\xi_0)-\tfrac{3}{5}\xi_{HF}]^1$$
$$=(0.339\pm 0.014)\times 10^{-16}\ \text{cm}^2.$$

This compares favorably with the theoretically computed[1] value of $Q_e=0.31\pm 10^{-16}$ cm^2. Improved values of spin-spin

and spin-rotational magnetic interaction constants have been obtained for both H_2 and D_2. From the spin-spin constant for H_2 a value of the internuclear distance has been calculated.

* This work was partially supported by the joint program of the ONR and AEC.
[1] N. F. Ramsey, Phys. Rev. **78**, 221 (1950).

G8. Sign Determination for Molecular Magnetic Moments.* C. K. JEN, J. W. B. BARGHAUSEN, AND R. W. STANLEY, *The Johns Hopkins University.*—The sign of the molecular magnetic moment can be determined by noting the asymmetry of the microwave Zeeman pattern due to a circularly polarized wave.[1] Circular polarization is produced from initial linear polarization by a mica phase-shifter or a squeezed section of wave guide. The absorption cell, formed by a short section of round wave guide, is placed in the center of a solenoid, which furnishes a steady magnetic field up to about 2500 oersteds. It has been found that either the $\Delta M=+1$ or the $\Delta M=-1$ Zeeman transitions can be completely suppressed by using the circularly polarized wave with a definite sense of rotation relative to the direction of the magnetic field. The signs of the rotational magnetic moments of ammonia and water molecules have both been found to be positive, in agreement with current concepts.

* Supported by Bureau of Ordnance, U. S. Navy, under Contract NOrd-7386.
[1] An earlier work has been done by J. R. Esbach, MIT thesis, December, 1950.

G9. Pressure-Broadening of Absorption Lines.* STANLEY BLOOM AND HENRY MARGENAU, *Yale University.*—Elementary perturbation theory is used to derive a formula for the intensity distribution of a pressure-broadened absorption line. To obtain a correct result it is necessary to calculate the probability of collision-induced transitions, not between the states of an isolated molecule as is customary, but between the unsharp energy states which characterize the molecule by virtue of its collisions with others. Unless the statistical matrix is taken diagonal the intensity distribution is of apparently meaningless complexity. Our result is similar to that obtained by Anderson[1] for emission lines, but it contains an anti-resonant term. Complete reduction to Anderson's formula occurs under two conditions: 1. The broad lines are sufficiently far apart to escape overlapping when broadened. 2. The absorbed light has a random distribution of phases, over which an average can be taken. Our method does not, however, seem to produce the correct numerical factor needed for detailed balancing between absorption and emission at all frequencies.

* Supported by the ONR.
[1] P. W. Anderson, Phys. Rev. **76**, 647 (1949) (Eq. (2)).

G10. Further Studies of *l*-Type Doubling Transitions in HCN and DCN.* THOMAS L. WEATHERLY, EDWARD R. MANRING, AND DUDLEY WILLIAMS, *Department of Physics and Astronomy, The Ohio State University.*—Absorption lines caused by direct transitions between *l*-type doubling levels have been observed for $J=9$, 10, and 11 for HCN and $J=10$, 11, and 12 for DCN. The observed frequencies $\Delta\nu$ and the resulting q-values defined by $q=\Delta\nu/J(J+1)$ are listed in Table I. The values of q calculated from Nielsen's expression[1]

TABLE I. *l*-type doubling transitions in HCN and DCN.

Molecule	Rotational level J	Observed frequency (mc/sec)	q-value (mc/sec)
HCN	9	20,181.39±.15	224.23*8*
HCN	10	24,660.40±.10	224.18*5*
HCN	11	29,585.12±.20	224.13*0*
DCN	10	20,454.58±.15	185.95*1*
DCN	11	24,539.20±.10	185.90*3*
DCN	12	28,992.55±.20	185.85*0*

are $q=226.2$ mc/sec for HCN and $q=183.6$ mc/sec for DCN. Thus the observed q-value for HCN is slightly lower than the calculated value, and the observed q-value for DCN is slightly higher than the calculated value. The q-values obtained from the observed spectra show a slight decrease with increasing J.

* This work was done in connection with Contract AF 19(122)-13 between Air Force Cambridge Research Center and The Ohio State University Research Foundation.
[1] H. H. Nielsen, Phys. Rev. **78**, 296 (1950).

G11. The Microwave Spectrum of a Slightly Aspherical Top—the Structure and Dipole Moment of Sulfuryl Fluoride.* ROBERT M. FRISTROM,† *Harvard University.*—The microwave spectrum of the slightly aspherical rotor, sulfuryl fluoride, has been investigated. Seven lines were found in the twenty- to thirty-thousand-megacycle region. Six of these lines were assigned to $J=1\rightarrow2$ and $2\rightarrow3$ rotational transitions of the molecule $S^{32}O_2F_2$ and the other to the $1_{11}\rightarrow2_{12}$ transition of $S^{34}O_2F_2$. These lines can be fitted to within the limits of experimental error (0.002 percent) with the following reciprocal moments of inertia:

$a_{32}=5139.77$ mc $\quad$ $a_{34}=5139.77$ mc
$b_{32}=5077.81$ mc $\quad$ $b_{34}=5073.10$ mc
$c_{32}=5057.22$ mc $\quad$ $c_{34}=5052.51$ mc.

Structural parameters were determined from these moments and the assumption of C_{2v} symmetry. The latter was confirmed by intensity measurements.

S−O 1.370±0.01A $\quad$ S−F 1.570±0.01A
O−S−O angle 129°38′±30′ $\quad$ F−S−F angle 92°47′±30′.

The S−O distance differs by −0.06A from the published electron diffraction value. Measurements on stark lobes of the three $1\rightarrow2$ transitions of $S^{32}O_2F_2$ gave a quantitative check of the assignment and a value of 0.228 Debye unit for the dipole moment.

* This work was supported by the Navy Department through the ONR under Task Order V.
† Present address: The Johns Hopkins University, Applied Physics Laboratory, Silver Spring, Maryland.

G12. Microwave Spectrum and Structure of Ozone.* RICHARD H. HUGHES.—A study has been made of the rotational spectrum of ozone between 8000 and 43,000 mc. The $2_{0,2}\rightarrow1_{1,1}$ line was found at 42,833 mc and the $3_{1,3}\rightarrow4_{0,4}$ at 11,073 mc. Using the frequencies of these lines and values of the asymmetry parameter δ between 0.01596 and 0.01600, moments of inertia were calculated which have been used to predict correctly the frequencies of seven other strong lines of J's between 9 and 23 to within ±200 mc. Calculations have not been made to account for two other observed lines of medium intensity and four of weak intensity. The calculated Stark effects of the two low J lines are consistent with the observed. Because of zero point vibrations, three moments of inertia slightly inconsistent with a planar structure are obtained. Assuming a planar structure, and taking the moments of inertia two at a time, the following range of values were obtained for the parameters of an isosceles triangle: the length of the two equal sides = 1.276−1.279A°; the apex angle = 116.5 −117.0°. The bond distance agrees well with that given by electron diffraction† but the angle differs considerably from the electron diffraction value of 127±3°. The dipole moment is 0.65±0.05 Debye.

* The early phase of this work was supported in part by the ONR when the author was in the Chemistry Department at Harvard University.
† W. Shand and R. A. Spurr, J. Am. Chem. Soc. **65**, 179–81 (1943).

G13. Microwave Absorption Spectrum of H_2O_2. J. T. MASSEY AND D. R. BIANCO, *The Johns Hopkins University.**—Utilizing an experimental sampling technique developed for the purpose, four absorption lines of the hydrogen peroxide molecule have been found at frequencies of approximately

14,830, 22,050, 27,638, and 35,912 mc. Using a dc field with a small 100 kc ac field superimposed, the Stark effect of the four lines has been studied and it has been found that all of the lines exhibit a quadratic Stark effect. It has been possible to completely resolve the Stark components of the first three of the four lines. There is considerable evidence that the H_2O_2 molecule has a nonplanar structure[1,2] and should possibly exhibit torsional oscillation.[3,4] The method outlined by Koehler and Dennison[5] is being applied to this model and calculations are also being made on a planar model in an attempt to correlate the observed microwave spectrum with the molecular structure.

* This work was supported by the U. S. Navy, Bureau of Ordnance under Contract NOrd-7386.
[1] W. G. Penney and W. B. B. M. Sutherland, J. Chem. Phys. **2**, 492 (1934).
[2] Lu, Hughes, and Giguère, J. Am. Chem. Soc. **63**, 1507 (1941).
[3] L. R. Zumwalt and P. A. Giguère, J. Chem. Phys. **9**, 458 (1941).
[4] P. A. Giguère, J. Chem. Phys. **18**, 88 (1950).
[5] J. S. Koehler and D. M. Dennison, Phys. Rev. **57**, 1006 (1940).

FRIDAY AFTERNOON AT 2:00

Sherman, Louis XVI Room

(ENRICO FERMI presiding)

Mesons and Cosmic Rays

H1. The Interaction of Charged π-Mesons with the Deuteron. W. B. CHESTON,* *University of Rochester.*—Calculations on the interaction of a charged meson of positive energy with the deuteron have been carried out in the conventional weak-coupling pseudoscalar theory for both direct and gradient couplings. The nucleon-nucleon interaction has been treated phenomenologically and the "impulse" approximation[1] employed. The processes considered were radiative absorption, charge-exchange scattering, and elastic and inelastic scattering; the nonradiative absorption results have already been published.[2] The ratio {σ nonradiative/σ radiative} in the pseudoscalar theory is essentially constant over a meson energy interval 0–25 Mev in contrast to the pseudovector theory. The differential cross section for charge-exchange scattering has a minimum in the forward direction, but otherwise mirrors the behavior of the charge-exchange scattering from a single nucleon target.[3] The elastic and inelastic scattering differential cross sections are peaked in the forward direction for direct coupling and at right angles for gradient coupling. For both types of coupling, the energy dependence of the total cross section is similar to the dependence of the single nucleon cross section.[3]

* Present address: Washington University, St. Louis, Missouri.
[1] G. Chew, Phys. Rev. **80**, 196 (1950).
[2] W. Cheston, Phys. Rev. **83**, 1118 (1951).
[3] Ashkin, Simon, and Marshak, Prog. Theor. Phys. **5**, 634 (1950).

H2. Charged π Meson Production in D and Pb at 90° from a 381-Mev Proton Beam.* M. M. BLOCK, S. PASSMAN, AND W. W. HAVENS, JR., *Columbia University.*—The differential cross sections for the production of charged π-mesons in D and Pb at (90±5)° from a 381-Mev proton beam have been obtained. Nuclear emulsions imbedded in tapered copper absorbers are exposed to mesons produced by bombardment of targets by the internal circulating proton beam of the Nevis cyclotron. The irradiation geometry we have previously described has been modified to provide better energy resolution. The deuterium cross section was obtained by using a deuterated paraffin target and subtracting the known carbon cross section. The absolute cross sections were obtained by monitoring the C^{11} activity production in the target or in a polyethylene foil. Preliminary results are shown in Table I.

TABLE I.

Element	90°π^+ cross section, integrated over meson energy	90°π^- cross section integrated over meson energy
D	$(2.8\pm1.2)\times10^{-28}$ cm^2-ster^{-1}	$(2.5\pm2.0)\times10^{-29}$ cm^2-ster^{-1}
Pb	$(11.7\pm4.5)\times10^{-28}$ cm^2-ster^{-1}	$(4.0\pm3.0)\times10^{-28}$ cm^2-ster^{-1}

Theoretical calculations for the production of π^+ mesons in a heavy element have been extended to include deuterium. Comparison of the calculations with experiment and the implications as to nuclear forces will be discussed.

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

H3. Interactions of Pi-Mesons in Carbon.* H. BYFIELD, J. KESSLER, AND L. LEDERMAN, *Columbia University.*—The scatterings and absorptions of pi-mesons (62±10 Mev) in carbon were studied in a 16-in. cloud chamber. Momenta of mesons incident upon and scattered from a single 2 g/cm^2 carbon plate were determined with a precision of about 10 percent. A total of about 500 nuclear events produced by both π^+ and π^- mesons consisted of elastic scatterings, inelastic scatterings[1] and stars with two to zero prongs. The latter (apparent stoppings) were restricted to a central fraction of the illuminated region to minimize confusion with out-scatterings. An angular distribution for elastic scattering of the π^- mesons is obtained which is strongly peaked forward, drops to a plateau of 5 mb/sterad at 60° and rises to 9 mb/sterad for backward scattering. We find

$$\int_{10^\circ}^{180^\circ} \sigma_{\text{elas}}(\theta)d\Omega = 204\pm18 \text{ mb}.$$

These results are in agreement with those obtained from counter studies.[2] The inelastic ($\Delta E>15$ Mev) angular distribution has a valley centered about 90°, probably because of the thickness of carbon plate and has a total cross section of 39±8 mb. The total absorption cross section (excluding elastic scatters <60°) is 244±20 mb. Fast protons ($E>40$ Mev) are observed in 11 percent of the stars. The total cross sections for π^+ interactions are very similar and these results will be detailed.

* Assisted by the joint program of the ONR and AEC.
[1] Bernardini, Booth, Lederman, and Tinlot, Phys. Rev. **82**, 105 (1951).
[2] Isaacs, Sachs, and Steinberger, this meeting.

H4. Elastic Scattering of Negative Pions in Carbon.* P. ISAACS, A. SACHS, AND J. STEINBERGER, *Columbia University.*—The elastic scattering of 62- and 90-Mev negative pions in carbon has been measured. Mesons defined in a two-counter telescope are scattered in a carbon plate and detected in two scintillation counters, with sufficient absorber between the counters to accept mesons only with energy greater than 56 and 79 Mev, respectively, for the two incident beams. Angular distributions for both beams show (a) Coulomb scattering at small angles with a gradual transition to diffraction scattering between 10 and 15 degrees, (b) a broad minimum in the 90-degree region with a differential cross

section of about 2×10^{-27} cm²/steradian, and (c) a slight rise in cross section for backward angles. For incident mesons of 90 ± 5 Mev, the integrated elastic cross sections are $2.4\pm.3\times10^{-25}$ cm² between 15 and 180 degrees and $2.2\pm.3\times10^{-26}$ cm² between 70 and 180 degrees, compared to the inelastic cross section of $3.08\pm.13\times10^{-25}$ cm². The 62-Mev results are in agreement with those of cloud-chamber experiments performed in this laboratory.[1]

* Research assisted by the ONR and AEC.
[1] Byfield, Kessler, and Lederman, Bull. Am. Phys. Soc. **26**, No. 6, Abstract H2 (1951) (this meeting).

H5. Lifetime of the Pi-Meson.* L. LEDERMAN, H. BYFIELD, AND J. KESSLER, *Columbia University.*—The decay-in-flight of 62-Mev pi-mesons in the gas of a 16-in. magnet cloud chamber has yielded[1] a value for the lifetime of the negative pi-meson. This value has been improved by increased statistics and better knowledge of beam impurities. The best present value is $2.85\pm.25\times10^{-8}$ sec. The lifetime of the positive pi-meson has been determined in a similar manner. The π^+ beam is obtained simply by reversing the field of the cyclotron magnet, the cloud-chamber location remaining fixed. The scanning and geometrical corrections were carried out in the same way as for the negatives.[1] Electron contamination is obtained from scattering plate data and electronic experiments and is taken as <2 percent. The mu meson contamination is assumed the same as in the π^- beam. With these assumptions, the ratio of π^+ to π^- lifetimes is: $\tau^+/\tau^-=1.01\pm0.11$.

* Assisted by the joint program of the ONR and AEC.
[1] Lederman, Booth, Byfield, and Kessler, Phys. Rev. **83**, 685 (1951).

H6. A Photographic Study of $\pi\rightarrow\mu\rightarrow\beta$-Decay.* H. J. BRAMSON, A. M. SEIFERT, AND W. W. HAVENS, JR., *Columbia University.*—Work previously reported[1] on the β-spectrum from μ-meson decay and on the search for anomalous μ-meson ranges from $\pi\rightarrow\mu$ is being continued. To date, some 1500 $\pi\rightarrow\mu$-decays have been observed where the μ-meson ends in emulsion 0.6 mm or 1 mm thick. Since a nearly monoenergetic monodirectional acceptance of π-mesons is achieved by suitable collimation,[2] mesons can be identified as π or μ before the apparent decay with an uncertainty of no more than one part in 10^3. A search was made for decay ranges shorter than 450 microns. One such event has been found: where the μ-meson has a range of 235 microns. Multiple scattering measurements of the β-tracks to determine their energy are in progress. Current data yield substantially the same spectrum presented earlier,[1] indicating a finite cut-off at the high energy end. The results of increased statistics will be presented.

* This research is being assisted by the joint program of the ONR and AEC.
[1] H. J. Bramson and W. W. Havens, Jr., Phys. Rev. **83**, 861 (1951).
[2] H. Friedman and L. J. Rainwater, Phys. Rev. **81**, 644 (1951).

H7. Annihilation Radiation from μ^+ Mesons. M. H. JOHNSON, *Naval Research Laboratory.*—The scheme $\mu^++e^-\rightarrow A\rightarrow2\gamma$ represents annihilation of a μ^+ meson through the intermediate state A. As intermediate states for which the transformation of rest mass to radiation is allowed, consider the three possibilities: $A_1=e^++e^-$; $A_2=\mu^++\mu^-$; and $A_3=\pi^\circ$. Radiation theory in the first two cases and the experimental π° lifetime in the third approximately determine transition matrix elements from A to the final state. The absence of experimental evidence for the transformations $\mu^+\rightarrow e^++\gamma$, $\mu\rightarrow e^-+\gamma$ and $\pi^\circ\rightarrow\mu^++e^-$, serve to set approximate upper limits on the transition matrix elements from A to the initial state. An upper limit to the annihilation rates in all three cases of 10^{-7} sec^{-1} can be so established for an electron density 10^{24} cm^{-3}, in comparison to the observed decay rate 10^6 sec^{-1}.

H8. Relative Pair Production Cross Section in the Region 50 to 300 Mev.* C. R. EMIGH, *University of Illinois.*—A cloud-chamber survey has been made of pairs produced in Al, Ag, and Au foils by an x-ray beam from the 300-Mev betatron. Two foils were placed parallel and spaced 14 cm apart in the chamber to intercept the same x-ray beam. The ratio of pairs produced in one foil to those produced in the other was determined. All possible combinations and relative positions of the foils were used during the experiment. Preliminary results of 36,000 pairs analyzed to date give for the pair-production cross section of Au to Al the values of $.89\pm.02$ for 50 to 100 Mev, $.85\pm.03$ for 100 to 150 Mev, $.89\pm.04$ for 150 to 200 Mev, and $.78\pm.1$ for 200 to 300 Mev. The ratio of Ag to Al is $.94\pm.02$ for 50 to 100 Mev, $.92\pm.03$ for 100 to 150 Mev, $.91\pm.04$ for 150 to 200 Mev, and $.84\pm.09$ for 200 to 300 Mev. The ratios are low compared with the Bethe-Heitler theory, approximately 6 percent for Au to Al and 3 percent for Ag to Al.

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

H9. Penetrating Showers under Hydrogen and Heavier Elements Observed in a Cloud Chamber at Sea Level.* A. B. WEAVER AND MARCEL SCHEIN, *University of Chicago.*—Local penetrating showers produced by ionizing and nonionizing radiation in various materials above a cloud chamber were studied. The chamber was located at sea level and was operated in a field of 9270 gauss. The materials placed above the chamber to generate the penetrating showers were: (1) liquid hydrogen averaging 2 g/cm²; (2) paraffin, 40 g/cm²; (3) carbon, 57.3 g/cm²; (4) aluminum, 92.5 g/cm²; and (5) lead, 168 g/cm². Some of the events observed and the information obtained concerning nucleon-nucleon collisions will be discussed.

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

H10. A Study of Penetrating Showers Produced in Be, Carbon, and Lead at Sea Level. L. GRODZINS, G. DEL CASTILLO, AND W. Y. CHANG, *Purdue University.*—The equipment used for the 11 months investigation was a counter controlled cylindrical cloud chamber (12 in. diam, 8 in. deep) as previously reported.[1] Three plates, the upper two of Be, 4.8 g/cm² each, and the lowest of Pb, 17 g/cm², were placed inside the chamber for the full 11 months. 43 g/cm² of C was placed above the chamber for the first 6 months and 43 g/cm² of Pb placed there for the remaining 5. Defining a penetrating particle as one which passes through the 17 g/cm² Pb plate without multiplication and without scattering through more than 20°, the results for the multiplicity of charged particles in the first gas space below the origin of the shower can be summarized as follows (in each shower at least one particle penetrates 110 g/cm² Pb below the chamber).

No. of parts/shower		2	3	4	5	6	7	8	9	10	15	av. mult.
No. of showers observed	Be	45	12	3	1	2						2.5
	C	52	21	3	5	1	1				1	2.8
	Pb	47	15	3	2	2	1	1	1	1		2.8

The multiplicity distribution in each element is generally compatible with the theory of multiple production by primary nucleons of a few Bev energy.

[1] G. Del Castillo and W. Y. Chang, Phys. Rev. **81**, 323 (1951).

H11. Two Cosmic-Ray Decreases Associated with the Geomagnetic Storms and Sunspot Activity of May and June, 1951.* R. L. CHASSON, *University of California.*—Continuous records of the total and hard (20-cm lead absorber) sea-level cosmic-ray intensity have been made in Berkeley, starting November, 1950. The apparatus consists of four geometrically identical wide-angle triple-coincidence counter telescopes, two for each radiation component. Correlations between intensity fluctuations and atmospheric and geomagnetic disturbances

have been made. A considerable intensity decrease started on May 23, 1951, followed on May 25 by a magnetic storm. The intensity then slowly returned to its pre-storm value. The May 23 decrease coincided with the disappearance around the West limb of the giant sunspot group Mt. Wilson 10662 (May 9–May 23). A larger, more persistent intensity decrease started June 11, 1951. A magnetic storm occurred June 17, in the middle of the period of the large intensity decrease. The passage across the disk of the giant sunspot group Mt. Wilson 10692 (June 12–June 25) coincided with the period of the latter decrease. Such a pre-storm decrease of intensity has been noted previously,[1] also in conjunction with unusual sunspot activity and accompanying geomagnetic disturbances.

* Work performed under auspices of the joint program of the ONR and AEC.

[1] A. Duperier and M. McCaig, Nature **157**, 477 (1946).

H12. Analysis of the Nucleonic Component Using Neutron Latitude Variations.* S. B. TREIMAN,† *University of Chicago.*—A function, $S_A(N, x)$, is defined which gives the rate of production of neutrons per gram of air at depth x arising from a unit vertical flux of primary cosmic ray particles of atomic weight A and momentum to charge ratio N. Using the Simpson[1] neutron latitude curve for 312 g-cm^{-2}, and the Winckler[2] primary spectrum, a geomagnetic analysis gives the function $S(N, x) = \Sigma_A f_A(N) S_A(N, x)$, where $f_A(N)$ is the fraction of primaries of atomic weight A. It is found that $S(N, x)$ is almost independent of N for N between 10 and at least 13.6 Bev/c. From available data[3] it appears that the $f_A(N)$ are almost independent of N in this range. It is then shown, assuming high energy collisions behave like single nucleon-nucleon interactions, that the $S_A(N, x)$ are, for all A, almost independent of energy for primary nucleon energies between 4 and at least 12.7 Bev, and for x at least between 20 and 600 8-cm^{-2}.

* Assisted in part by the Office of Air Research, USAF.

† Predoctoral Fellow.

[1] J. A. Simpson, Jr., Phys. Rev. **76**, 569 (1949); Phys. Rev. (to be published).

[2] Winckler, Stix, Dwight, and Sabin, Phys. Rev. **79**, 656 (1950).

[3] B. Peters, *Progress in Cosmic Ray Physics* (North Holland Publishing Company, Amsterdam) (to be published).

H13. Experiments on the Solar-Produced Component of the Cosmic Radiations.* J. A. SIMPSON, W. FONGER, AND L. WILCOX, *University of Chicago.*—Time-dependent changes of the primary cosmic-ray radiations have been investigated in the low and intermediate energy range by measuring the neutron intensity of the nucleonic component. Continuous observations were made simultaneously at several latitudes and altitudes and the momentum distributions of the changes were investigated in high altitude aircraft operating between 40° and 69°N. Twenty-seven day periodic recurrences of increased primary intensity have been found and associated with large disturbed regions on the sun. Hence, they coincide with a 27-day solar spin. These regions are identified by the observation of solar radio noise bursts and by visual flare effects. During the first half of 1951, differences of intensity within 30 days became as large as the order of 10 percent at sea level. The increases were observed simultaneously at all recording stations. Some local regions in the sun persisted for at least three solar rotation periods and were accompanied by increased primary radiation. It is shown that these increases are neither a result of geo-dipole magnetic field changes nor dependent on the properties of the atmosphere. Changes of intensity of primaries with momenta >5(Bev/c) have been observed. It is shown that these appreciable increases of primary cosmic-ray intensity are associated with local regions on the sun.

* Assisted in part by the Office of Air Research, USAF.

H14. Heavy Metal Cosmic Ray Primaries. HERMAN YAGODA, *National Institutes of Health.*—Microscopic examination of 2-mm thick emulsion castings exposed in the stratosphere at elevations reaching 110,000 ft provides evidence for a group of heavy primaries of $Z>26$. In a preliminary report[1] an exceptionally heavy track was identified as of charge 49 ± 3 on the basis of thin-down length. Scanning at low power for heavy primaries ($Z\geq6$) whose tracks terminate in the emulsion indicates that at atmospheric depths of 7 to 15 g.cm^{-2} heavy metal nuclei ($Z>34$) have an abundance about 0.3 that of the Fe-Co-Ni group. These tracks are characterized by dense cylinders of secondary ionization up to 30 microns diameter and pronounced thin down lengths of 500 ± 100 microns. The flux of heavy metal nuclei is rapidly attenuated in traversing the upper atmosphere, as the examination of an equal volume of emulsion flown at 80,000 ft failed to reveal tracks heavier than $Z=26$. One event shows the fragmentation of a heavy metal nucleus into a narrow angle beam comprised of $\mathrm{Fe}\mp2\mathrm{Ne}\mp\mathrm{Be}+\mathrm{He}+\mathrm{H}$ nuclei which indicates a charge on the incident particle of 53 ± 6. The method has been checked on an event showing the breakdown of an iron nucleus (identified by delta-ray count) into $\mathrm{O}+\mathrm{Be}+\mathrm{Li}+11\mathrm{H}$ particles. The presence of heavy metal nuclei is this indicated both by the ionization along their tracks and charge conservation in nuclear interactions.

[1] H. Yagoda, Phys. Rev. **80**, 753 (1950).

FRIDAY AFTERNOON AT 2:00

Sherman, Grey Room

(G. WENTZEL presiding)

General Physics—Theoretical

I1. Classical Meson Theory and Action at a Distance. PETER HAVAS, *Lehigh University.*—A theory of action at a distance was developed recently for particles interacting through neutral meson fields.[1,2] This work has now been extended to charged fields in the classical counterpart of the charge symmetrical theory of Kemmer. The field theoretical equations of motion, found recently for retarded interaction through vector meson fields,[3] contain integrals over the past and entire motion for the retarded and half-retarded, half-advanced interaction, respectively. As in the neutral theory we omit them from the postulated equations of motion of action at a distance. A variational principle is developed for these new equations with symmetric interaction; the equations of motion, of the variation of charge and of the fields of the "adjunct" field theory are derivable from it. An energy-momentum tensor and a charge-current vector guaranteeing detailed conservation laws are defined. The application of the Wheeler-Feynman method to the equations of both theories is discussed. Analogous results are obtained for scalar mesons.

[1] P. Havas, Phys. Rev. (to be published) (vector and scalar mesons).

[2] H. Kanazawa, Prog. Theor. Phys. **5**, 1050 (1950); H. Steinwedel and S.-B. Heidelberger, Akad. Wiss., math.-naturwiss. Kl., 281 (1950) (vector mesons).

[3] K. J. Le Conteur, Proc. Cambridge Phil. Soc. **45**, 429 (1949).

I2. The Contribution of Interaction Moments to Nuclear Magnetic Moments. MARC ROSS, *University of Wisconsin.*—The spin-antisymmetric interaction moment[1,2] can contribute to the static magnetic dipole moments of nuclei and to magnetic transitions in nuclear isomers and in the two- and three-body systems. This interaction moment is determined from the three-body moment anomaly and may be considered to represent a modification of neutron intrinsic moment due to the proximity of protons, and vice versa. The contribution to the magnetic moments of nuclei has been calculated, using wave functions prescribed by M. G. Mayer's spin-orbit coupling model. A very simple expression for the moment is found. For odd proton nuclei the resulting contribution is roughly $+\frac{1}{2}$ n.m. for $j=l+\frac{1}{2}$ and $-\frac{1}{4}$ n.m. for $j=l-\frac{1}{2}$; and the same with opposite sign for odd neutron nuclei. Thus the spin-antisymmetric contribution is small, and of such a sign as to increase the magnitudes of theoretically predicted moments. The results suggest that if interaction effects lead to important modiffications of nuclear moments these may only show up in the heavy nuclei.

[1] N. Austern, Phys. Rev. **81**, 307(A) (1951).
[2] R. G. Sachs and N. Austern, Phys. Rev. **81**, 705, 710 (1951).

I3. Covariant Theory of Damping. J. C. PIRENNE,* *National Research Council, Canada.*—The covariant construction of the S-matrix in the Cayley form in terms of a hermitian operator K, will be compared with previous non covariant formulations of Heitler and Pauli. New general formulas for K will be presented, connecting Gupta's and Miyazima's results.[1,2] The nth order approximation of K and S are closely related, and K is generally expressed in terms of the anti-hermitian parts of the S_p of order $p \leqslant n$.

* Associate Fellow of the "Fonds National de la Recherche Scientifique," Bruxelles, Belgique.
[1] S. Gupta, Proc. Cambridge Phil. Soc. **47**, 454 (1951).
[2] Miyazima, Prog. Theor. Phys. **5**, 152 (1950).

I4. On the Thermodynamics of Fields. A. E. SCHEIDEGGER AND C. D. MCKAY, *Queen's University.*—In connection with our recent investigations on quantum statistics of Fields,[1] some further results have been obtained. Firstly, one expects that the formalism for constructing the thermodynamic functions of vacuum fields breaks down if the fields are treated classically. This is explicitly shown to be the case. Secondly, it has been observed that the thermodynamic functions of the relativistic fields do not yield the thermodynamic functions of the nonrelativistic fields if c approaches infinity. It is shown that this is the result of the presence of the rest mass of the particles in the hamiltonian. A subtraction procedure to subtract this rest mass has been developed and it is shown that the latter introduces a new parameter into the thermodynamic functions which is very similar to the temperature. Thirdly, it is of some interest to calculate the fluctuations of the thermodynamic variables around their expectation values. Thus expressions for the vacuum fluctuations of quantized fields have been obtained.

[1] A. E. Scheidegger and C. D. McKay, Phys. Rev. **83**, 125 (1951).

I5. On an Extension of the Classical Infinitesimal Group of Canonical Transformations.—D. C. RIVIER,* *National Research Council, Canada.*—By introducing a generalization of the classical poisson bracket of two functions of canonical variables, it is possible to extend the infinitesimal group of canonical transformations. The generalized poisson bracket satisfies all the main identities of the usual poisson bracket, chiefly the jacobi identity. This is a necessary condition for the generalized set of transformations to form an infinitesimal continuous group. The main difference between the new and the usual poisson bracket is that the new one involves derivatives of order higher than the first. The set of generalized infinitesimal transformations may be put in a one-one correspondence with the infinitesimal group of unitary transformations of quantum mechanics, in such a way that correspondence between generalized poisson bracket and commutators is valid generally. This gives a different approach to the problem of correspondence between classical and quantum mechanics.

* Postdoctoral Fellow of the "Commission Suisse des Bourses de Mathematiques et de Physique."

I6. On the Geometry of the Group-Space of the Proper Lorentz Group. E. J. SCHREMP, *Naval Research Laboratory.*—The group-space of the proper Lorentz group possesses a complex 3-dimensional projective representation P_3 (or 4-dimensional affine representation S_4) whose geometry is determined by the algebra of complex quaternions, and whose homogeneous (or nonhomogeneous) coordinates are the coordinates (q^0, q^1, q^2, q^3) of a general complex quaternion q.[1] In S_4, which is a form of "spin-space," there are embedded two conjugate systems of imprimitivity of varieties of four real dimensions. These systems furnish two alternative representations of the tangent space to space-time, each having (in the terminology of projective relativity) and imaginary "index." The *external motions* induced in either system by the transformations of the corresponding parameter group comprise the proper Lorentz and imaginary gauge transformations. The *internal motions* simultaneously induced in the varities of the given system comprise certain real Euclidean rotations and real gauge transformations. Physically, the space P_3 (or S_4) may be identified with the relativistic phase space (i.e., external momentum space and internal configuration space) of a single non-localizable elementary particle. The abovementioned geometrical motions then serve to describe the physical motions of the particle's distribution in phase.

[1] See E. J. Schremp, *On the Interpretation of the Parameters of the Proper Lorentz Group*, Proceedings of the 1950 International Congress of Mathematicians, Cambridge, Massachusetts (to be published).

I7. A Remark on the Fundamental Reversibility and the Phenomenological Irreversibility. SATOSI WATANABE, *Wayne University.*—It is obvious that "irreversibility of observation" in the sense of von Neumann's theory,[1] is the essential element that enables us to deduce irreversible conclusions from the reversible theoretical scheme of quantum physics. Born's new "quantum-theoretical deduction"[2] of the H-theorem, which does not refer to observations, is shown to be no exception to this general remark. The problem then concerns how and where this irreversibility of observation should be introduced in the process of deduction to obtain results in forms as conformable as possible to the phenomenological theory. Some fundamental postulates and practical prescriptions will be given, rationalizing the deduction of irreversible results, such as the H-theorem, the "retarded" potential,[3] etc., from the reversible basic laws.

[1] J. von Neumann, Math. Grundl. d. Quantenm. Berlin, 1932.
[2] M. Born, Ann. Inst. Henri Poincaré **11**, 1 (1949).
[3] S. Watanabe, Phys. Rev. (to be published).

I8. Do Coulomb Fields Signal Faster than Light? D. I. CAPLAN AND F. J. BELINFANTE, *Purdue University.*—The coulomb field $\mathbf{E}_{\text{II}} = -\nabla V = -\nabla \Phi_{\text{ret}} - \partial \mathbf{A}_{\text{retII}}/c\partial t$ acts instantaneously by $V(\mathbf{x}, t) = \int d^3x' \rho(\mathbf{x}', t)/r$. The retardation effects of Φ_{ret} and $\mathbf{A}_{\text{retII}}$ cancel each other because of the supposed analytical character of the charge and current distributions in deterministic field theory. Measure at P the field $\mathbf{E}_{\text{II}}$ of an electron instantaneously at T, which traversed the past light cone from P at R, and was scattered at S between R and T. Φ_{ret} and $\mathbf{A}_{\text{retII}}$ would be useful for calculating $\mathbf{E}_{\text{II}}(P)$ only if at R we could predict outcome of deterministically predetermined scattering. *Quantum mechanically,* we might break the analytical behavior of the expectation values by "reduction" of the wave function after S. If we often measure simultaneously $\mathbf{E}_{\text{II}}(P)$ and scattered electron position at T, then

$\langle \mathbf{E}_{\text{II}}(P)\rangle_{\text{Av}} = \langle -\nabla \Phi_{\text{ret}} - \partial \mathbf{A}_{\text{retII}}/c\partial t\rangle_{\text{Av}}$ unless we select *a posteriori* those cases for which the electron is found at T in a definite position T', for which selected cases $\langle \mathbf{E}_{\text{II}}(P)\rangle_{\text{Av}} = \langle -\nabla V_{T'}\rangle_{\text{Av}}$. Conversely, a measured $\mathbf{E}_{\text{II}}(P)$ may give more probability for electron to be at T' than, say, T''; but it gives no unmistakenly certain instantaneous signal at P of electron position at T.

I9. Gauge-Independent Quantized Bopp Theory. FREDERIK J. BELINFANTE, *Purdue University.*—The unperturbed energy of Bopp's electrodynamics is $\mathfrak{IC}_0 = \mathfrak{IC}_{\text{maxwell}} - \mathfrak{IC}_{\text{Proca}} + \mathfrak{IC}_{\text{matter}} - \mathfrak{IC}_{\text{vacuum}}$. In interaction representation we quantize Bopp's unperturbed field using opposite-to-usual sign for the neutral-Proca-field commutators. The interaction with matter is $W = W_{\text{maxwell}} - W_{\text{Proca}}$. We choose for W_{maxwell} the interaction operator of gauge-independent quantum electrodynamics. As this separates the coulomb field, it is convenient to do the same in W_{Proca}. Thence $W = (\mathbf{E}_{\text{II}}\cdot\mathfrak{e}/4\pi) - \mathbf{j}\cdot\mathfrak{a}$, where $\mathbf{E}_{\text{II}}(\mathbf{x}) = -\nabla \int d^3\mathbf{x}'\rho(\mathbf{x}')/r$, $\mathbf{j} = e{:}\psi^\dagger\boldsymbol{\alpha}\psi{:}$, $\mathfrak{e} = \mathfrak{E} - \mathfrak{F}$, $\mathfrak{a} = \mathfrak{A} - \mathbf{U}_{\text{II}}$, if $\mathfrak{E}$, $\mathfrak{B}$ $(= \text{curl}\mathfrak{A})$ is the transverse maxwell field, and $\mathfrak{F}$, $\mathbf{G}$ $(= \text{curl}\mathbf{U})$ is the Proca field (with potential four-vector $\mathbf{U}$, Y). The integrability (covariance) of the generalized Schrödinger equation with W is shown. In Heisenberg representation, $\mathfrak{B}$ forms a tensor with $\mathfrak{E} = \mathfrak{E} + \mathbf{E}_{\text{II}}$, and $\mathbf{G}$ with $\mathbf{F} = \mathfrak{F} + \mathbf{E}_{\text{II}}$, and Bopp's interactions appear in the field equations for $\mathbf{E}$, $\mathfrak{B}$, $\mathbf{F}$, $\mathbf{G}$, $\mathbf{U}$, Y. We make the expectation value of the energy positive definite by imposing the new covariant auxiliary condition for Proca as for maxwell field: $\mathfrak{E}^{(+)}\Phi = \mathfrak{A}^{(+)}\Phi = \mathfrak{F}^{(-)}\Phi = \mathbf{U}^{(-)}\Phi = 0$, with $\mathfrak{E}$, $\mathfrak{A}$, $\mathfrak{F}$, $\mathbf{U}$ in interaction representation and the state vector Φ in Heisenberg representation. The expectation values of the fields are then retarded maxwell and Proca fields as discussed by Bopp.[1]

[1] F. Bopp, Ann. Physik **38**, 345 (1940); **42**, 575 (1943).

I10. Information, Logic, and Physics. JEROME ROTHSTEIN, *Evans Signal Laboratory.*—Relativity made it clear that no geometry has *a priori* validity for physics but rather that world geometry is a physical theory whose truth resides in successfully coordinating experience. We assert the same for all mathematics and logic. Logic can be formulated via the calculus of classes (sets, ensembles). Its empirical justification stems from the fact that measurement or observation of objects to grouping them in classes satisfying relations isomorphic to those of the calculus of sets. Classification involves choice from a number of alternatives, i.e., acquiring information or measuring.[1] Conventional logic is inapplicable when classifications cannot be made (operationally undefined) or when set algebraic relations are violated. Quantum logics of Reichenbach, and von Neumann and Birkhoff, correspond, respectively, to these cases; complementarity retains conventional logic by excluding features generating these cases. Such non-Aristotelian logics may be useful for unmeasurables (e.g., virtual processes, certain divergencies, Einsteinian completion of quantum theory) and for other sciences.

[1] J. Rothstein, Phys. Rev. **82**, 322(A) (1951).

I11. A Relation between Planck's Constant and the Gravitational Constant (to be read by title). B. LIEBOWITZ, *New York.*—As a basis for a different approach to atomic theory I have proposed[1] an atomic model comprising electromagnetic wave fields associated with the nucleus and its circumnuclear electrons. The existence of such wave fields depends on inhomogeneity of space around the nucleus. This inhomogeneity concept stems from the Einstein effect, hence a theory based on it must involve the gravitational constant G, at least implicitly. But eventually such theory must involve h, hence a relation between h and G is expected. By purely dimensional and numerical procedure one easily finds

$$G \cong 3\pi e^2/2[mN\alpha(1+\alpha)]^2,$$

or

$$\alpha \cong \frac{1}{2}\left\{\left[1+\frac{4e}{Nm}\left(\frac{3\pi}{2G}\right)\right]^{\frac{1}{2}} - 1\right\},$$

where $\alpha = 2\pi e^2/hc$, mN is "atomic weight" of electron, etc. Calculating α, hence h, from $G = 6.673\times10^{-8}$,[2] using atomic data of December, 1950, h comes out about 0.05 percent low. Aside from uncertainties in G, this discrepancy could conceivably be partly the result of differences between macroscopic values of atomic constants (e.g., deflection) and microscopic values (e.g., spectroscopic) arising from this inhomogeneity.

[1] B. Leibowitz, Phys. Rev. **64**, 294 (1943); *ibid.* **66**, 343 (1944).
[2] Bur. Standards RP, 1480 (1942).

FRIDAY AFTERNOON AT 2:00

Morrison, Mural Room

(J. C. BOYCE presiding)

Invited Papers. Topics in Nuclear Physics.

J1. Evidence for Strong Spin Orbit Coupling from the Low States of Light Nuclei. R. K. ADAIR, *University of Wisconsin.* (30 min.)

J2. Recent Experiments in Neutron Physics: Neutron-Proton Capture Cross Section; Neutron-Electron Interaction; Total Cross Sections in the Kev Region; Capture Gamma-Rays. BERNARD HAMERMESH, *Argonne National Laboratory.* (30 min.)

J3. Systematics of Isomer Energy Levels. R. D. HILL, *University of Illinois.* (20 min.)

J4. Beta Spectra. LAWRENCE M. LANGER, *University of California, Los Alamos Scientific Laboratory.* (30 min.)

SATURDAY MORNING AT 9:00

Sherman, Crystal Room

(K. LARK-HOROVITZ presiding)

Semiconductors, I

K1. Quantum Theory of the Internal Field in an Idealized Crystal.* D. L. DEXTER AND W. R. HELLER, *University of Illinois.*—The quantum-mechanical polarizability of an idealized crystal is calculated by the semiclassical method. The excited states which contribute are exciton states as deduced from the crystal model first discussed by Frenkel[1] and result from the transition dipole-dipole interactions of excited atoms.[2] A generalization of the Lorentz "local field" emerges naturally. Corrections to the Lorentz value for the polarizability of an atom within the crystal, $\alpha_a/[1-(4\pi n_0/3)\alpha_a]$, where α_a is the polarizability of an isolated atom, arise from three main sources: (1) exchange effects, (2) higher order terms in the atomic interactions than dipole-dipole terms, and (3) the existence of more than one excited state to which the atom can make virtual transitions. A brief discussion is given of these corrections, which are important in real crystals; it is shown that caution must be exercised in obtaining meaningful oscillator strengths from absorption data, and, in particular, that the local field correction differs for different energy levels.

* Research supported by the ONR.
[1] J. Frenkel, Phys. Rev. **37**, 17, 1276 (1931); Physik. Z. Sowjetunion **9**, 158 (1936).
[2] W. R. Heller and A. Marcus, Phys. Rev. (to be published). See also Phys. Rev. **82**, 315 (1951).

K2. Electronic States in Crystals under Large Over-All Perturbations.* PAULA FEUER AND HUBERT M. JAMES, *Purdue University.*—Solutions of the three-dimensional Schroedinger equation are considered for a periodic potential modified by a perturbing potential. A method of Slater[1] has been modified and used to develop the theory of large over-all perturbations, such that the energy lies close to one permitted band in one region of the crystal and close to a second permitted band in another. The solution of the perturbed periodic Schroedinger equation is expressed as $\psi=\Sigma_k\{\phi_1(r_k)a_1(r-r_k)+\phi_2(r_k)a_2(r-r_k)\}$, where $a_1(r-r_k)$ and $a_2(r-r_k)$ are functions localized about the Kth atom of the crystal, appropriate to the first and second permitted bands, respectively. Difference equations are derived for the coefficients ϕ_1 and ϕ_2. The theory has been applied to a one-dimensional crystal in a uniform electric field, using the narrow band approximation; an expression has been obtained for the probability for an electron to cross a forbidden energy band.

* Work supported in part by the Signal Corps.
[1] J. C. Slater, Phys. Rev. **76**, 1592 (1949).

K3. Experimentally Derived Configurational Coordinate Curves. CLIFFORD C. KLICK, *Naval Research Laboratory.*—If it is assumed that the configurational coordinate curves of the ground and excited states of a system are parabolas and that under these conditions the system can be treated as a quantized harmonic oscillator, the constants necessary to describe both curves may be determined from experiment. Seven optical measurements which can be applied are: wavelengths of the absorption and emission peaks, band width of the absorption and emission bands at low temperatures, relative change in band width with temperature of the absorption and emission bands, and variation with temperature of luminescence efficiency or decay constant. For systems in which the effective mass of the vibrating system in both its ground and excited state is unknown, six experiments determine both the curves and the unknown masses. If the mass is assumed, four experiments suffice. The latter case is illustrated by computations on thallium-activated potassium chloride and the results compared with the curves computed theoretically by Williams.[1]

[1] F. E. Williams, J. Chem. Phys. **19**, 457 (1951).

K4. Pulse-Heating of Bulk Semiconductors.* J. HIRSCH† and R. B. MCQUISTAN, *Purdue University.*—The pulse heating method by Ehrenberg and Hirsch[1] to obtain resistance-temperature characteristics of semiconducting films at heating rates up to 5000°C/sec has been adapted for the study of bulk specimens of semiconducting materials. A heating current of rectified, unfiltered ac is passed through the specimen. During the intervals when the heating current is interrupted a constant, nonheating "measuring" current is passed through the specimen and the potential developed between two probes is applied to the vertical deflection plates of a cathode-ray tube via a direct coupled amplifier. The resistance thermometer, a transparent gold film on 0.001-in. mica, is cemented to the sample with mica as electrical insulator between sample and gold film. The voltage developed by a constant measuring current across the gold film is applied to the vertical deflection plates during the periods when heating current flows. A typical pulse-heating record for an N-type Ge sample will be shown (heating pulse 0.2 sec, horizontal sweep frequency 3 c/sec). A $\log\rho$ *vs* $1/T$ graph can be obtained by a "static method" in a few minutes.

* Supported by Signal Corps Contract W36-039-SC-38151.
† To be introduced by K. Lark-Horovitz.
[1] J. Hirsch, Ph.D. thesis, University of London (1950) (Proc. Phys. Soc. (London) **64**, 700 (1951)).

K5. The Effect of Certain Group IV Oxides on the Permitivity and Loss Tangent of Barium Titanate. GRAHAM W. MARKS AND LESTER A. MONSON, *U. S. Navy Electronics Laboratory.*—Respective mixtures of barium titanate and the dioxides of silicon, titanium, zirconium, cerium, and thorium were prepared in from 0.5 to 50 mole percentages of the latter. Chemically pure materials were used. The powders were pressed and air-fired for one to two hours at 1200 to 1360°C. After silvering, the ceramics were placed in a constant temperature oven and the permittivity and loss tangent determined over the range from 30° to 170°C at a frequency of 1000 cycles. The densities were measured at room temperature. Values of the permittivity were then corrected for the porosity of the ceramics. The Curie point of pure barium titanate is 127.8 ±0.2°C and is lowered by all of the oxides except silica which raises it. The permittivity is also lowered. Calculations of the permittivities of these ceramics from the relationship, $\ln\epsilon=v_1\ln\epsilon_1-v_2\ln\epsilon_2$ (in which ϵ is the permittivity of the mixture, ϵ_1 and ϵ_2 that of the respective pure constituents, and v_1 and v_2 the respective volume fractions) did not, in general, yield values which corresponded to those determined experimentally.

K6. Isotope Effect in RbD_2PO_4. B. T. MATTHIAS, *Bell Telephone Laboratories.*—Crystals of a tetragonal modification of RbD_2PO_4 were grown and the dielectric constant parallel to the c-axis was determined as a function of temperature. RbD_2PO_4 becomes ferroelectric below 218°K which is about 5° higher than the Curie point of KD_2PO_4 at 213°K. The Curie points of KH_2PO_4 and RbH_2PO_4 are at 123°K, and 147°K, respectively. It is interesting to note that the higher the critical temperature of a ferroelectric transition, the smaller

the influence of isotopic change, which may reflect the increasing importance of kT *vs* the zero point energy. Rochelle salt[1] (shift of upper Curie temperature from 297°K to 308°K) furnishes another instance.

[1] A. N. Holden and W. P. Mason, Phys. Rev. **57**, 54 (1939).

K7. Optical and Electrical Behavior of Lanarkite. L. M. Roth, K. W. Meissner, and K. Lark-Horovitz, *Purdue University.*—Photoconductive oxidized PbS films show* on the surface (electron diffraction pattern) lanarkite ($PbO \cdot PbSO_4$) whereas the bulk of the material (x-ray diffraction pattern) consists of PbS. Using single crystals of lanarkite mounted between a quartz plate and an aluminum sheet with a very small slit, the optical transparency in the visible and ultraviolet, as well as in the near infrared, has been determined. An unpolished single crystal and a thinner polished single crystal were used. The polished crystal showed continuous absorption at wavelengths below 3020A and the unpolished below 3400A. This corresponds to an absorption edge of about 3.6 electron volts. The absorption in the infrared, tested by M. Becker, with the same equipment used for the testing of the lead sulfide cells themselves, showed that lanarkite shows no absorption up to about 5μ. Lanarkite itself is an insulator and no photoconductive properties in the material were detected with the same illumination with which lead sulfide films show photoconductive response.

* Daughty, Lark-Horovitz, Roth, and Shapiro, Phys. Rev. **79**, 203(A) (1950).

K8. Magnetoresistive Effect in Impurity Semiconductors.* W. J. Whitesell, II, and V. A. Johnson, *Purdue University.*—A number of investigations have demonstrated the dependence of the resistivity of semiconductors upon magnetic field. The theoretical treatment of this effect due to Harding[1] is based upon the Lorentz solution of the Boltzmann equation and involves the assumption that the mean-free-path of the conduction electrons is independent of their energies. Actually these electrons are subject to various scattering mechanisms, especially lattice scattering with an energy-independent mean-free-path and Rutherford scattering with a mean-free-path proportional to the square of energy. The integrals giving the dependence of ρ upon H have been evaluated on the basis that $1/l=1/l_L+1/l_I$. In this way the dependence of $\Delta\rho/\rho_0$ on H has been found as the proportion of impurity scattering rises from 0 to 100 percent. There is a general tendency for the quantity $\Delta\rho/\rho_0$ divided by H^2 to increase with increasing proportion of impurity scattering. When compared with experimental data for typical germanium samples,[2] the theoretical curve is much too low at room temperature, but gives increasingly better fit as the temperature decreases.

* Supported in part by Signal Corps Contract.
[1] J. W. Harding, Proc. Roy. Soc. (London) **A140**, 205 (1933).
[2] J. W. Cleland, M. S. thesis, Purdue University, 1949; I. Estermann and A. Foner, Phys. Rev. **79**, 365 (1950).

K9. Comparison of the Adiabatic and Isothermal Hall Effects.* V. A. Johnson and F. L. Shipley, *Purdue University.*—The interpretation of observed Hall effect data involves the question of whether the conditions of the experiment are those assumed in the derivation of the theoretical expression. One usually employs the isothermal Hall coefficient, derived on the assumption that the transverse electric current, the longitudinal and transverse temperature gradients are zero. Another theoretical expression is the adiabatic Hall coefficient, based on zero values of transverse electric and thermal currents and longitudinal temperature gradient. Both of these expressions depend upon the nature of the scattering encountered by conduction electrons. The difference between the adiabatic and isothermal Hall coefficients has been evaluated as a function of the ratio of the resistivity due to impurity ion (Rutherford) scattering to the total resistivity. This difference increases with increasing impurity scattering, but is only a few thousandths percent for a high thermal conductivity semiconductor in the temperature range such that conduction electron density is almost independent of temperature. However, this difference increases at low temperatures due to the more rapid change of carrier density with temperature; a similar effect occurs at high temperatures due to the production of intrinsic carriers. Differences arising from existing temperature gradients in the nonisothermal, nonadiabatic case have been considered.

*Supported by a Signal Corps Contract.

Saturday Morning at 9:00

Sherman, Grey Room

(Maria Goeppert-Mayer presiding)

Nuclear Physics: Miscellaneous Topics

L1. Absolute Backscattering Coefficients for Positrons and Electrons. Howard H. Seliger, *National Bureau of Standards.*—Backscattering coefficients for isotropic sources of Na^{22} positrons and P^{32} electrons have been measured for backing materials ranging from carbon to lead using 4π absolute beta-counters.[1] In these experiments the source and backing were placed inside the sensitive volume of the counter so that all backscattered particles were detected. Although the ratio of electron to positron backscattering is always greater than 1 as reported previously,[2] the individual values obtained with the 4π counter differ considerably for both electrons and positrons from those obtained in the original experiment, where only a small solid angle ($\sim\frac{1}{4}\pi$) was subtended by a G-M counter at 90° to the face of the backing. Further experiments with both electrons and positrons indicate a marked anisotropy in the angular distribution of the backscattered radiation, with a maximum for high Z and a minimum for low Z, at 90° to the plane of the backing. In addition, the backscattered radiation becomes more energetic at smaller angles with the backing. Experimental details and a qualitative explanation of these results will be presented.

[1] H. H. Seliger and L. Cavallo, J. Research Natl. Bur. Standards **47**, 41 (1951).
[2] H. H. Seliger, Phys. Rev. **78**, 491 (1950).

L2. Measurements of the Relative Transmission of Beta-Particles Through Geiger-Müller Counter Windows.* Chia-hua Chang and C. Sharp Cook, *Washington University.*—The measurements of the relative transmission of beta-particles through Geiger-Müller counter windows has been reported at previous meetings of the American Physical Society.[1] The work since then has been concentrated on the relative transmission of negatrons and positrons through windows of two electrically different materials. An aluminum

foil of thickness 7.2 mg/cm² and a mica sheet of thickness 5.9 mg/cm² have been used for these investigations. The radioactive sources employed are Cu^{61} for positrons and P^{32} for negatrons. It has been found that the aluminum window has almost the same transmission curve for both positrons and negatrons except for a slight deviation in its lower energy region, which might be explained as having been caused by a possible instrumental distortion. However, the mica window gives a distinctly smaller transmission for positrons than for negatrons throughout the entire energy range studied. This makes it appear that the transmission curve for nonconducting G-M tube windows may be different for positrons than for negatrons. A possible explanation for this phenomenon will be presented.

* Assisted by the joint program of the ONR and AEC.
[1] C. H. Chang and C. S. Cook, Phys. Rev. **83**, 872 (1951); also Phys. Rev. **79**, 244 (1950).

L3. Ranges of High Energy Electrons in Water. J. OVADIA, J. W. BEATTIE, AND J. S. LAUGHLIN, *University of Illinois.*—A betatron was used to produce an external electron beam continuously variable from 5 to 22 Mev. Well-collimated beams of different cross-sectional areas were incident on a water chamber. The distribution of ionization in the water was measured with a small ion chamber (0.381 cm³) whose position was varied by remote control. Typical ionization distributions as a function of electron energy will be presented. These distributions can be converted into essentially number of electrons *versus* range plots by correcting for the specific ionization of the electrons as a function of energy.[1] The extrapolated ranges from these plots should correspond to the "practical maximum range" defined by Bleuler and Zünti.[2,3] The variation of these experimental extrapolated ranges with energy in water has been compared with the predicted maximum theoretical ranges.[4,5] The calculated ranges which include density effects agree more closely with our experimental values.

[1] R. B. Brode, Rev. Modern Phys. **II**, 222 (1939).
[2] E. Bleuler and W. Zünti, Phys. Acta **19**, 375 (1946).
[3] F. L. Hereford and C. P. Swann, Phys. Rev. **78**, 727 (1950).
[4] E. Fermi, Phys. Rev. **57**, 485 (1940).
[5] O. Halpern and H. Hall, Phys. Rev. **73**, 477 (1948).

L4. The Energy Loss of Monoenergetic Electrons in Carbon and Water. JOHN I. LODGE AND FRANK L. HEREFORD, *University of Virginia.*—A number of experiments[1] have confirmed the Halpern-Hall and Wick calculations of the polarization reduction in ionization and energy loss of charged particles traversing condensed media. These two calculations differ somewhat, particularly in the predicted magnitude of the polarization effect in carbon. Previous measurements[2] of the stopping power of carbon relative to that of water (S_{H_2O}/S_C) for 1–10 Mev electrons favored the Halpern-Hall results. This measurement has been repeated with significant improvements in experimental technique. In particular the beta-spectrum of P^{32} magnetically analyzed to provide a homogeneous, gamma-free beam of electrons was employed, and the C and H_2O sample thicknesses were determined with greater precision. As in the previous work,[2] multiple and backscattering effects were essentially eliminated through choice of equal sample thicknesses as measured in radiation lengths. The influence of these effects was investigated experimentally. A typical result for 0.75-Mev electrons yields $S_{H_2O}/S_C = 1.12 \pm 0.02$ in best agreement with the Wick result.

[1] W. L. Whittemore and J. C. Street, Phys. Rev. **76**, 1786 (1949); E. Pickup and L. Voyvodic, Phys. Rev. **80**, 89 (1950).
[2] F. L. Hereford, Phys. Rev. **74**, 574 (1948).

L5. Calorimetric Determination of the Roentgen for 400-kv X-Rays. J. S. LAUGHLIN, J. W. BEATTIE, AND J. OVADIA, *University of Illinois.*—The unit of ionization, the roentgen, has customarily been employed to measure the output of x-ray generators. The conversion of this ionization unit into actual energy flux for experiments is difficult, since this requires an accurate knowledge of the spectral distribution in addition to other factors related to the absorption of the x-rays in various media. In order to measure the energy flux directly an improved version of the calorimetric method employed for 22.5-Mev x-rays[1,2] has been applied to a 400-kv self-rectifying x-ray generator with an inherent filtration of 1.75 mm copper. This calorimeter employed thermistors as temperature sensitive elements. Its construction and calibration will be described. For 400-kv x-rays the energy flux was measured as 2800±60 ergs/cm²-roentgen. Comparison with theoretical calculations will be made.

[1] J. S. Laughlin and J. W. Beattie, Phys. Rev. **83**, 231(A) (1951).
[2] J. S. Laughlin and J. W. Beattie, Rev. Sci. Instr. **22**, 572 (1951).

L6. Calorimetric Calibration of a Secondary Standard for 150–317 Mev Bremsstrahlung.* P. D. EDWARDS, *University of Illinois.*—A secondary standard, 4-in. diameter, parallel plate ionization chamber consisting of a 0.016-in. Al center foil separated by 0.052-in. air gaps from 0.25-in. Cu front and back plates and adopted for use with a Victoreen M-70 electrometer has been calibrated calorimetrically. Absolute calibration was performed with an improved Pb block calorimeter of a type previously used[1] except that the temperature sensitive elements were changed to thermistors after the method of Laughlin. Five-minute irradiations were used with a maximum of 33 milliwatts emerging from the 0.5 in. diameter collimator. With present knowledge of corrections to be applied, the results are accurate to 4 percent.

Mev	ergs/esu per cm air (NTP)
317	6400
300	6600
250	5510
200	4930
150	4720

* Assisted by the joint program of the ONR and AEC.
[1] E. L. Piper and G. H. Price, Phys. Rev. **81**, 309 (1951).

L7. The "Effective" Atomic Numbers of Materials for Various γ-Ray Interactions.* G. J. HINE,** *Massachusetts Institute of Technology.*—The "effective" atomic number of a material composed of several elements cannot be expressed by a single number. For each of the different processes by which γ-rays can interact with matter, the various atomic numbers in the material have to be weighted differently. The "effective" atomic number for photoelectric absorption of γ-rays follows as $\bar{Z}_{\text{photoel.}} = (\Sigma_i p_i Z_i^{3.1})^{1/3.1}$. If only light elements with an atomic number $2 \geqslant Z \geqslant 20$ are involved, p_i is the fraction by weight of each element present in the material. The "effective" atomic number for pair production is given by $\bar{Z}_{\text{pair}} = \Sigma_i p_i Z_i$. Finally, it will be shown that an "effective" atomic number for the backscattering of secondary electrons emmitted from a material under γ-irradiation can be defined as $\bar{Z}_{\text{backsc.}} = \pi_i (Z_i+1)^{p_i} - 1$. For a medium composed of several elements, $\bar{Z}_{\text{backsc.}}$ is always smaller than $\bar{Z}_{\text{pair}}$. Experimental results will be presented for the relative intensity of backscattered secondary electrons produced by the Co^{60} γ-rays in materials of known and unknown composition; for bones a value of $\bar{Z}_{\text{backsc.}} = 11.5 \pm 0.5$ has been determined.

* Assisted by the joint program of the ONR and AEC.
** Special Research Fellow of the National Cancer Institute, Bethesda, Maryland.

L8. The Neutrons from the Disintegration of the Separated Isotopes of Silicon by Deuterons.* C. E. MANDEVILLE, C. P. SWANN, AND S. D. CHATTERJEE,† *Bartol Research Foundation of the Franklin Institute.*—Thick targets of the oxides of the separated isotopes of silicon have been irradiated by deuterons of energy 1.4 Mev, supplied by the Bartol Van de

Graaff statitron. The resulting neutron spectra have been observed by recording recoil protons, knocked on in the forward direction in Eastman NTA plates. Q-values obtained at zero and ninety degrees with the incident deuterons are as follows:

Reaction	Q-values (Mev)
$Si^{28}(D, n)P^{29}$	0.29
$Si^{29}(D, n)P^{30}$	3.27, 2.52, 1.81, 1.27
$Si^{30}(D, n)P^{31}$	4.92, 4.59, 3.73, 2.70, 1.51

The estimated probable error in all Q-values is ± 0.04 Mev.

* Assisted by the joint program of the ONR and the AEC.
† Calcutta, India. Guest physicist, Bartol Research Foundation, 1951.

L9. The Angular Distribution of Prompt Neutrons in the Fission of Pu^{239}. J. S. FRASER, *Chalk River Laboratory.*—Collimated fission fragments from a 200 $\mu g/cm^2$ layer of Pu^{239} exposed to slow neutrons from the thermal column of the N.R.X. pile were detected and identified in energy in a gridded ionization chamber. Coincident prompt fast neutrons in a given direction were counted by proton recoils in a fixed electron collecting chamber filled with methane. The fission chamber was rotated to set the collimator at various angles to the direction of the fast neutron chamber. Angular distributions of the fast neutrons relative to the collimated fission fragments are presented. For curve (a) only the light fragments were selected; for curve (b) all fragments were allowed. Curve (a) yields a ratio $N(0°)/(180°) = 1.72 \pm 0.06$. Assuming for analysis the same energy distribution of the neutrons in the frame of reference of a fragment as for U^{235} fission, it appears that the light fragment emits about 30 percent more neutrons than the heavy. Curve (b) gives $N(0°)/N(180°) = 0.992 \pm 0.020$ which checks the experimental technique. It also gives $N(0°)/N(90°) = 4.35 \pm 0.15$. Observations at 0° and 180° to the light fragment as a function of fragment kinetic energy indicate a lower average of this energy in the most probable neutron emitting mode than in the most probable splitting.

L10. New Medium Mass α-Emitters.* K.-H. SUN, F. A. PECJAK, AND B. JENNINGS, *Westinghouse Research Laboratories* AND A. J. ALLEN, *University of Pittsburgh.*—A general consideration of nuclear shell configulrations and α-emitting systematics of heavy nuclei[1] (near $Z = 82$ and $N = 126$) led previously to the discovery of severa new α-emitters in the lanthanide rare earth region[2,3] ($N = 82$). We have now extended the work to the region of other closed shell nuclei of lower masses ($N = 50$) and found two new α-emitters by bombarding $_{44}Ru$ with a 30-Mev α-beam. Their half-lives were found to be ~4 min and ~4 hr. In addition, another new α-emitter with a ~8-hr half-life was also observed when $_{78}Pt$, an element having isotopes low in neutron content, was bombarded by a 30-Mev α-beam. This should be grouped with the α-emitters obtained by bombarding $_{79}Au$ and $_{80}Hg$ with 200-Mev protons.[2] Work is being continued in obtaining better values for half-lives and in searching for more new α-emitters by extending the technique of α-bombardments to elements in the other closed shell regions (Ca, Ni, Sn, etc.) and to those having isotopes with low neutron content (Hg, Os, W, Hf, Dy, Pd, etc.).

* Assisted by the joint program of the ONR and AEC.
[1] Perlman, Ghiroso, and Seaborg, Phys. Rev. **77**, 26 (1950); also a much earlier work of W. Heisenberg, Report du VII^me Congres Solvay (1934).
[2] Thompson, Ghiroso, Rasmussen, and Seaborg, Phys. Rev. **76**, 1406 (1949); Rasmussen, Reynolds, Thompson, and Ghiorso, Phys. Rev. **80**, 475 (1950).
[3] Sun, Pecjak, Jennings, Allen, and Nechaj, Phys. Rev. **82**, 772 (1951).

L11. On the Fine Structure of the Alpha-Particles of Po^{210}. S. DE BENEDETTI AND G. H. MINTON, *Carnegie Institute of Technology.*—The well-established gamma-radiation from Po^{210} must be accompanied by a weak group of low energy alpha-particles which had not yet been detected despite of several attempts to study the fine structure of this isotope.[1] A coincidence method has been applied to the investigation of this problem. A source of Po was located in a liquid scintillant and the distribution in pulse height of the alpha-particles was studied. In this way the height corresponding to the main alpha-group was determined. Subsequently we studied the height of the alpha-pulses in coincidence (resolving time 3×10^{-9} sec) with the gamma-rays detected by means of another thick scintillation counter. A clear shift of the position of the peak was observed, corresponding to the known energy of the gamma-rays. An attempt was made to determine the half-life of the excited state for which an upper limit of 10^{-9} sec was found. At present some experiments for the study of the alpha-gamma angular correlation are under way.

[1] W. Y. Chang, Phys. Rev. **69**, 60 (1946). W. G. Wadey, Phys. Rev. **74** 1846 (1948).

L12. Atomic Masses of Titanium, Vanadium, and Chromium.* T. L. COLLINS, A. O. NIER, AND W. H. JOHNSON, JR., *University of Minnesota.*—In a recent communication[1] we reported on the packing fractions of elements from sulfur to scandium as measured with a double focusing mass spectrometer. This study has now been extended to include all of the isotopes of titanium and chromium and the abundant isotope of vanadium. Measurements were made by doublet comparisons with hydrocarbon fragments. Using $H^1 = 1.008146 \pm 3$ and $C^{12} = 12.003842 \pm 4$, we find the following packing fractions: Ti^{46}, 7.18 ± 0.01; Ti^{47}, 7.09 ± 0.02; Ti^{48}, 7.68 ± 0.01; Ti^{49}, 7.43 ± 0.01; Ti^{50}, 7.85 ± 0.01; V^{51}, 7.74 ± 0.01; Cr^{50}, 7.58 ± 0.01; Cr^{52}, 8.26 ± 0.02; Cr^{53}, 7.98 ± 0.02; Cr^{54}, 8.09 ± 0.04. Results for iron and nickel will also be given.

* Supported by joint program of the ONR and AEC.
[1] Collins, Nier, and Johnson, Phys. Rev. **83**, 228(A) (1951).

L13. Atomic Masses of Xenon, Iodine, and Some Isotopes of Tin.* R. E. HALSTED, *University of Minnesota.*—The double-focusing mass spectrometer previously described[1] has been used to measure the masses of xenon, iodine, and some isotopes of tin by the doublet method, comparisons being made with hydrocarbon fragments. Using $H^1 = 1.008146 \pm 3$ and $C^{12} = 12.003842 \pm 4$, the following packing fractions ($\times 10^4$, all negative) were obtained:

Xe^{136}, 3.64 ± 0.01;	Xe^{134}, 3.88 ± 0.02;	Xe^{132}, 4.08 ± 0.01;
Xe^{131}, 4.06 ± 0.05;	Xe^{130}, 4.25;†	Xe^{129}, 4.18 ± 0.02;
Xe^{128}, 4.34 ± 0.01;	Xe^{126}, 4.38 ± 0.02;	Xe^{124}, 4.36 ± 0.02;
I^{127}, 4.30;†	Sn^{124}, 4.45 ± 0.02;	Sn^{122}, 4.71 ± 0.03;
Sn^{120}, 4.95 ± 0.03;	Sn^{119}, 4.94 ± 0.02;	Sn^{118}, 5.10 ± 0.03;
Sn^{117}, 5.09 ± 0.02;	Sn^{116}, 5.25;†	Sn^{115}, 5.20 ± 0.03.

Comparisons will be made with existing nuclear reaction and mass spectrographic data.

* Supported by joint program of the ONR and AEC.
[1] A. O. Nier and T. R. Roberts, Phys. Rev. **81**, 507 (1951).
† Tentative value.

SATURDAY MORNING AT 9:00

Sherman, West Room

(DONALD W. KERST presiding)

Gamma-Rays

M1. Gamma-Gamma-Coincidence Absorption and Angular Correlation of I^{131}. DANIEL SCHIFF, *University of Illinois.**—The gamma-rays emitted in the decay of I^{131} were investigated with sodium iodide scintillation counters. Absorption of the gamma-gamma-coincidences showed that at least 85 percent of these coincidences occur between the 80-kev and 284-kev lines. The coincidences remaining with thick absorbers, not accounted for by the 284-kev line and apparently caused by a harder component, were shown by critical absorption not to be connected with the 80-kev line. They are probably coincidences with the bremsstrahlung due to the beta-rays emitted by I^{131}. We conclude that the 638-kev line does not go to the 80 kev level as previously reported,[1,2] but leads to the ground state of Xe^{131}. Angular correlation measurements showed the coincidences between the 80-kev and 284-kev gammas to be isotropic within 3 percent. Assuming pure radiation, this characterizes the spin of the 80-kev level as $\frac{1}{2}$. However, the existence of interference due to a mixture of radiations may cause the correlation to vanish even if the spin of the 80-kev level is not $\frac{1}{2}$.

* Supported in part by the joint program of the ONR and AEC.
[1] Kern, Mitchell, and Zaffarano, Phys. Rev. **76**, 94 (1949).
[2] Bell, Cassidy, and Kelley, Phys. Rev. **82**, 103 (1951).

M2. Gamma-Gamma Coincidences in "Cs^{137}" and Fe^{59}. FRANZ R. METZGER, *Department of Physics, University of Illinois.**—Using sodium iodide scintillation counters, we have investigated several sources which, according to the presently accepted decay schemes, should not exhibit any gamma-gamma coincidences. Be^{7} was found to be free of such coincidences. However, in Cs^{137} as well as in Fe^{59} sources we found an appreciable number of gamma-gamma coincidences. In Cs^{137} sources, the coincidences are the result of Cs^{134} (2.3 years half-life) formed in a second-order reaction. In our source, obtained from Oak Ridge, the Cs^{134} activity was about two percent of the total activity. This amount of Cs^{134} is of the order of magnitude expected from known cross sections and the flux density of the pile. Measurements at different discriminator settings showed that in Fe^{59} the gamma-gamma coincidences occur between a 200-kev gamma-ray and a one-Mev radiation. A line corresponding to a 195 ± 10-kev gamma-ray was consequently found in a scintillation spectrometer. The 200-kev radiation is very likely the transition between the 1.3- and 1.1-Mev levels in Co^{59}. It occurs in 2.5 percent of all the Fe^{59} disintegrations.

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

M3. Angular Correlation of Rh^{106}. J. J. KRAUSHAAR, *Brookhaven National Laboratory.**—The spectrum of Rh^{106} has been analyzed by a NaI scintillation spectrometer. The energies and relative intensities of the five main gamma-rays have been determined and agree well with the values reported in the previous abstract. The partial decay scheme, consistent with the beta- and gamma-ray intensities, has been investigated in order to explain the discrepancy between the measured angular correlation[1] and the calculated one for a 0–2–0 quadrupole-quadrupole transition. The effect of the 1.04–0.51-Mev gamma-ray cascade in competition with the 0.62–51 cascade is to lessen the expected values of $\epsilon(\theta)$ for a 0–2–0 transition in proportion to the intensity, relative efficiency of the counters, and values of $\epsilon(\theta)$ for the competing cascade. The contribution of the 1.04–0.51 transition is not enough with these considerations to explain the discrepancy. It may be that a loss of memory in the angular correlation of the 0–2–0 transition is involved. The correlation of the higher energy cascade has been roughly determined by differential and integral discrimination.

* Under contract with the AEC.
[1] E. L. Brady and M. Deutsch, Phys. Rev. **78**, 5 (1950).

M4. Angular Correlation Between Inelastically Scattered Protons and Gamma-Rays from the 1.4-Mev Level in Mg^{24}.* H. E. GOVE AND A. HEDGRAN,† *Massachusetts Institute of Technology.*—A 7.8-Mev proton beam from the MIT cyclotron was used to bombard a thin isotopic magnesium target. Coincidences between inelastic protons from the 1.4-Mev level in Mg^{24} and the corresponding gamma-rays were measured as a function of proton angle for two gamma-ray angles (protons, gamma-rays and beam co-planar). The experimental equipment employed has been described previously,[1] the only modification being the NaI gamma-counter. For the case in which the gamma-counter makes an angle of $-90°$ to the incident beam the angular correlation exhibits a rather pronounced maximum for a proton angle of $+90°$ (protons and gamma-rays emitted back to back). For a gamma-angle of $-30°$ no large variation in correlation occurs. The angular distribution of the inelastic protons has also been measured and indicates the presence of angular momentum terms as high as three. The possibility of using such measurements as an independent check of previously measured spins of excited states and for predicting unknown spins will be suggested.

* This work was assisted in part by the joint program of the ONR and AEC.
† On leave from the Nobel Institute for Physics, Stockholm, Sweden.
[1] Boyer, Gove, Harvey, Deutsch, and Livingston, Rev. Sci. Instr. **22**, 311 (1951).

M5. Capture γ-Rays from Protons on N^{14}. C. H. JOHNSON, C. D. MOAK, AND G. P. ROBINSON, *Oak Ridge National Laboratory.*—The γ-ray spectrum has been observed for the resonant capture of protons by N^{14}. A thick TaN target was bombarded with 280-kev protons from the Cockcroft-Walton generator. Gamma-rays resulting from the capture of protons at the 277-kev[1] resonance entered a large NaI (Th) crystal at 0° to the proton beam. Scintillations produced in the crystal were detected by a type 5819 photomultiplier. Pulses from the photomultiplier were amplified with a linear amplifier and studied with a one-channel differential discriminator. Gamma-rays from Cs^{137} and Na^{22} served to calibrate the pulse heights in terms of energy. The resulting capture γ-ray spectrum shows six groups. The energies of these six γ-rays can be arranged to give the total excitation energy in O^{15} (7.61 Mev) only if there are three intermediate levels in O^{15} giving rise to three cascade processes of two γ-rays each. These three pairs of γ-ray energies are 0.75 and 7.0 Mev, 1.38 and 6.4 Mev, and 2.38 and 5.3 Mev. In each case the addition to 7.61 Mev is considered within experimental error.

[1] R. Tangen, Kgl. Norske Videnskab. Selskab, Skr. No. 1 (1946).

M6. Photodisintegration Thresholds of Beryllium and Deuterium.* J. C. NOYES,† J. E. VAN HOOMISSEN,‡ W. C. MILLER, AND B. WALDMAN, *University of Notre Dame.*—A 90-degree, two-foot radius, electrostatic analyzer has been used to measure the energy of the electrons from our electrostatic generator. This measurement depends on the machining

of the deflecting plates, the positioning of the components of the analyzer, and the determination of the deflecting voltage. The total error contributed by these factors is less than 0.1 percent. The entrance and exit slits were adjusted to give a resolution of 2 kev. X-rays produced in a thick gold target by the electron beam emerging from the analyzer disintegrated the beryllium and deuterium. The neutrons were detected by a BF_3 counter, and the x-rays were monitored by a G-M counter. The neutron yields at various electron energies up to 30 kev above the thresholds were extrapolated to zero. The neutron binding energies of beryllium and deuterium are 1.664 ± 0.002 Mev and 2.231 ± 0.003 Mev, respectively.

* Supported in part by the joint program of the ONR and AEC.
† AEC Predoctoral Fellow, now at Boeing Airplane Company, Seattle, Washington.
‡ Now at Sandia Base, Albuquerque, New Mexico.

M7. Cu(γ, d):(γ, p) Ratio.* WARREN H. SMITH, *Iowa State College.*—The relative abundance of photodeuterons from copper was determined by magnetic curvature and range measurements. 65-Mev bremsstrahlung struck an 18-mil copper foil in a 12-inch helium-filled cloud-chamber, situated in a 3470-gauss field and viewed stereoscopically. Tracks of length at least 8 cm ending in the illuminated region were measured. The mean magnetic rigidity, in an interval 4 to 14 cm from the end, was obtained for 70 tracks. Tracks of measurable length different from 14 cm thus required correction (<12 percent). The expected rigidity for protons and deuterons of such range is known from the gas stopping power (calibrated by Po α's). The expected spread from scattering is calculated. The data indicate the appearance of both masses, with respective $H\rho$ distributions separated by approximately twice their individual half-widths. The observed d/p ratio 0.5 ± 0.15 (for equal range and solid angle intervals) provides an independent check of high photodeuteron abundance.[1]

* Work was performed at the Ames Laboratory of the AEC.
[1] P. R. Byerly, Jr., and W. E. Stephens, Phys. Rev. **83**, 54 (1951).

M8. Photoprotons from Bismuth. M. ELAINE TOMS AND WILLIAM E. STEPHENS, *University of Pennsylvania.**—The high energy photoprotons from some medium weight elements[1] have seemed to show an angular variation which suggests that they were produced by a direct photoprocess. To check if this mechanism were present in heavy nuclei, for which the coulomb barrier would suppress lower energy evaporated photoprotons, we have looked for photoprotons from a one-mil foil of bismuth irradiated with x-rays from a 24-Mev betatron and recorded in nuclear emulsions. The photoproton yield observed is about 3×10^4 protons/mole/r, which is smaller than the anisotropic protons observed in Rh, Ag, and Cu.[1] This yield is of the order of magnitude of or somewhat smaller than the yield calculated with reasonable assumptions on the Weisskopf-Ewing model. The photoproton energy distribution has a peak near 11 Mev, somewhat higher than that calculated on this model. The angular distribution seems isotropic, within the rather poor statistical uncertainties of 20 percent. Thus we find no evidence for any direct photoeffect for protons from bismuth in this energy range.

* Supported by the Air Research and Development Command and the joint program of the AEC and ONR.
[1] Curtis, Hornbostel, Lee, and Salant, Phys. Rev. **77**, 290(L) (1950); B. C. Diven and G. M. Almy, Phys. Rev. **80**, 407 (1950); P. R. Byerly and W. E. Stephens, Phys. Rev. **83**, 54 (1951).

M9. Angular Distribution of Photofission Fragments from Thorium.* E. J. WINHOLD, P. T. DEMOS, AND I. HALPERN, *Massachusetts Institute of Technology.*—A 16-Mev x-ray beam from the M.I.T. Linear Accelerator has been used to produce fission in a thorium target. The fission fragments were collected on aluminum foils arranged about the target in such a way as to pick up the fragments emitted in various directions. After exposures to the beam for times ranging from 6 to 180 minutes, the foils were counted with Geiger counters for periods up to several days. The ratio of the activity observed at 90° to that observed at 0° to the x-ray beam seems to be independent of both the duration of the exposure and the time of the measurement after the exposure. When account is taken of the angular resolution of the foil arrangement, and if the distribution of the activity is assumed to follow an $a+b\sin^2\theta$ relationship, then $b/a=0.25\pm0.08$.

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

M10. Photofission of Uranium.* ROGER E. ANDERSON AND ROBERT B. DUFFIELD, *University of Illinois.*—The threshold for photofission of U^{238} has been measured by a catcher technique and found to be 5.2 ± 0.1 Mev. This is in disagreement with the value of 7.0 Mev predicted by the liquid drop model[1] but in agreement with an earlier experimental result obtained by a different method.[2] The cross sections for photofission of U^{238} and for the total photoneutron production from U^{238} have been determined up to 23 Mev. Both cross sections show maxima at approximately 15 Mev and decrease to small values at 23 Mev. This result is in agreement with the model proposed for photonuclear reactions by Goldhaber and Teller.[3] There is a sharp break in the photofission yield curve at 5.9 Mev, the threshold of the $U^{238}(\gamma, n)$ reaction.

* Assisted by the joint program of the ONR and AEC.
[1] S. Frankel and N. Metropolis, Phys. Rev. **72**, 914 (1947).
[2] Koch, McElhinney, and Gasteiger, Phys. Rev. **77**, 329 (1950).
[3] M. Goldhaber and E. Teller, Phys. Rev. **74**, 1046 (1948).

M11. Gamma-Ray Absorption Coefficients in the 5–10-Mev Energy Range.* E. S. ROSENBLUM, E. F. SHRADER, AND R. M. WARNER, *Case Institute of Technology.*—Gamma-ray absorption coefficients in lead and uranium are being investigated using radiation from the Case betatron. Collimation limits the beam to about a 0.6-degree cone; errors due to radiation scattered in the absorber are negligible. The radiation is analyzed with a magnetic pair spectrometer and a detection system consisting of stilbene crystals and RCA 5819 photomultipliers, providing an energy resolution of about 10 percent at 10 Mev and 15 percent at 5 Mev. A fast coincidence circuit, described previously,[1] having a resolving time of 5×10^{-9} second, gives a background of less than one percent of the counting rate when no absorber is in the beam. Preliminary measurement of the absorption coefficient in Pb at 10 Mev gives a value of 0.56 cm^{-1}, indicating that the correction to the theory at 10 Mev is of the same order of magnitude as that found by other investigators at higher energies. Results for Pb and U at 5 and 10 Mev will be presented.

* Work supported by the AEC.
[1] E. F. Shrader, Rev. Sci. Instr. **21**, 883 (1950).

SATURDAY MORNING AT 9:30

Sherman, Louis XVI Room

(J. H. VAN VLECK presiding)

Invited Papers

N1. UNESCO and International Cooperation in the Physics Sciences. RONALD FRASER, *International Council of Scientific Unions.* (20 min.)

N2. Photoelastic Analysis of Ultrasonic Waves. E. A. HIEDEMANN, *Michigan State College.* (30 min.)

N3. Recent Experiments with the University of Michigan Shock Tube. OTTO LAPORTE, *University of Michigan.* (30 min.)

N4. The Interaction of π-Mesons with Protons. HERBERT L. ANDERSON, *University of Chicago.* (30 min.)

SATURDAY AFTERNOON AT 2:00

Sherman, Crystal Room

(JOHN BARDEEN presiding)

Semiconductors, II

O1. Energy Levels in KCl. L. G. PARRATT AND E. L. JOSSEM, *Cornell University.**—Evidence is presented for the existence of discrete filled "ionization" levels below the filled $3p$ band of potassium and of chlorine in crystalline KCl in the immediate locale of a $1s$ vacancy. This evidence comes from observed shapes, widths, and energy positions of component lines in the $K\beta$ x-ray emission spectra. These lines were recorded with the newly constructed focusing crystal spectrometer previously described.[1] Also, evidence is presented for local discrete empty "excitation" levels below the ionization continuum. This evidence comes from an interpretation of the x-ray absorption spectra in the region of the K edge of potassium and of chlorine as recorded by Trischka.[2] Based upon these measurements and tentative interpretations, an energy level diagram for KCl is proposed to account for the component x-ray emission and absorption lines, and the enigmas of (1) the experimentally narrow β_1 line (0.92 ev full width at half-maximum for potassium and 0.67 ev for chlorine), (2) the unexplained component lines accompanying β_1, and (3) the absorption maxima and minima are tentatively resolved.

* Supported in part by the ONR.

[1] E. L. Jossem and L. G. Parratt, Phys. Rev. **79**, 210 (1950).

[2] J. W. Trischka, Phys. Rev. **67**, 318 (1945).

O2. Anionic Self-Diffusion and Electrical Conduction in Sodium Bromide. H. W. SCHAMP, JR.*—The diffusion coefficient of the radioactive bromide ion in sodium bromide was measured by evaporating a thin layer of sodium bromide containing the radioactive bromide ion onto one face of a single crystal of the compound, heating this exposed specimen for a definite length of time (360°C–688°C), cooling it, and then sectioning it to determine the distribution of radioactivity within the crystal. Above 450°C the results of the direct measurement of the diffusion coefficient are quantitative and can be expressed as $D_{Br}=50\exp(-2.02/kT)$ cm²/sec. It is shown that below this temperature the actual coefficient is certainly lower than the measured value. The diffusion coefficient calculated from conductivity can be expressed as $D_{con}=4.36\exp(-1.66/kT)$ at high temperatures and as $D_{con}=6\times10^{-6}\exp(-0.80/kT)$ at low temperatures. The ratio $D_{Br}/D_{con}=11.5\exp(-0.36/kT)$ is taken as a measure of the transport numbers in the range of temperatures from 500°C to 700°C. It is shown that at low temperatures the diffusion coefficient directly measured is at least 30 to 40 times smaller than the coefficient calculated from conductivity, and it is concluded that the existence of pairs is unlikely.

* AEC Predoctoral Fellow.

O3. The Effect of Pressure on the Position of the *F*-band in Alkali Halides. E. BURSTEIN, J. J. OBERLY, AND J. W. DAVISSON, *Naval Research Laboratory.*—The effect of hydrostatic pressure on the position of the F-band in NaCl, KCl, and KI has been investigated up to 2000 atmospheres. The measured shifts in the position of the F-band, like those due to temperature changes, are found to be larger than the values calculated from the known dependence of the position of the F-band on the lattice constant of the various alkali halides. Further, the ratio $\Delta E_{obs}/\Delta E_{calc}$ increases in the order KI $<$KCl$<$NaCl. In terms of the "particle-in-a-box" model for the F-center[1] the discrepancy between experimental and calculated values may be attributed to the fact that the trapped electron exerts a considerably smaller repulsion on its neighbors than the halogen ion it replaces, so that the neighboring alkali metal ions which make up the walls of the box in which the electron is trapped are displaced from their normal position in the lattice toward the electron. Preliminary calculations based on these considerations show that, other factors being equal, the shift in the F-band should increase with decreasing compressibility of the host crystal in agreement with the experimental results.

[1] E. Burstein and J. J. Overly, "Optical properties of F-centers at liquid helium temperatures," Low Temperature Symposium, National Bureau of Standards (1951).

O4. Rectification Effects in Diamond. G. W. CURL AND G. C. DANIELSON, *Iowa State College.*—Point contact rectification has been observed both in counting and in photoconducting diamonds. The counting rate and the photoconducting current are usually greatest when the probe is the positive electrode, but the degree of rectification varies greatly with different diamonds. In the case of photoconductivity, the rectification effect has been investigated by applying an alternating potential to a circuit consisting of a diamond and a capacitor in series. The direct current potential appearing on the capacitor is measured by an electrometer circuit. The de-

pendence of this direct current potential upon the magnitude and frequency of the applied potential will be shown.

O5. Infrared Absorption of Nucleon-Bombarded Silicon. I.* M. BECKER, H. Y. FAN, AND K. LARK-HOROVITZ, *Purdue University.*—Recent investigations show that the absorption in silicon, beyond 1.1 micron, rises again toward longer wavelengths and is smaller the higher the resistivity. It has also been found that the resistivity of both *n*- and *p*-type silicon increases upon irradiation with high energy nucleons. We have therefore investigated the infrared absorption of silicon bombarded by neutrons in the Oak Ridge reactor and by 10-Mev deuterons in the Purdue cyclotron. The effects of the bombardment by neutrons and deuterons are similar and are the same for *n* and *p*-type samples: (a) A new[1] narrow absorption band appears at 1.75 microns. It sharpens with decreasing temperature, the half-width at 100°K is about 0.6 of that at room temperature. Its peak shifts toward shorter wavelength with decreasing temperature and is moved to 1.65 microns at 100°K. (b) Except for the new band the longer wavelength absorption is reduced to very small values. (c) The absorption edge, shows an apparent shift toward longer wavelengths. A shift over 0.05 micron has been observed. Both *n*- and *p*-type samples have reached resistivities of the order 10^5 ohm-cm due the bombardments.

* Supported by a Signal Corps Contract.
[1] Lark-Horovitz, Becker, Davis, and Fan, Phys. Rev. **78**, 334(A) (1950).

O6. Infrared Absorption of Nucleon-Bombarded Silicon. II.* H. Y. FAN, *Purdue University.*—The reduction of long wavelength absorption to very small values is convincing evidence for ascribing the long wavelength absorption to free carriers. The new absorption band at 1.75 microns fits the usual expression of line broadening. As it sharpens with decreasing temperature, $\int \mu(\nu)d\nu$ for the band remains nearly constant. Therefore, this band may be due to electron transitions between discrete energy levels in the energy gap. The increase of resistivity of both *N* and *P*-type materials indicate that both[1] hole traps *A* and electron traps *B* are introduced by the bombardment. The new absorption band is due to excitations from *A* to higher discrete levels *A'* and/or due to excitations from lower discrete levels *B'* to *B*. From the high resistivities reached due to the bombardments and from the position of the new band the energies of these levels can be estimated. The apparent shift of the fundamental absorption edge seems to indicate that imperfections of the lattice introduced by bombardment give rise to changes in band to band excitation.

* Supported by a Signal Corps Contract.
[1] Reading Report, July, 1951, and Cleland, Crawford, Jr., Lark-Horovitz, Pigg, and Young, Jr., Phys. Rev. **83**, 312 (1951).

O7. Atomic Heat of Silicon and Germanium at Very Low Temperatures.* P. H. KEESOM AND NORMAN PEARLMAN, *Purdue University.*—The atomic heat of Si has been measured between 1–100°K and of Ge between 1–80°K. Between 1 and 4°K for Si: $C_v=6.5\times10^{-6}T^3+3.1\times10^{-5}T$ joules/degree mole and for Ge: $C_v=3.87\times10^{-5}T^3+2.6\times10^{-5}T$ joules/degree mole. Assuming the linear term in T is due to a source other than the lattice vibrations, the Debye temperature is constant below 4°K and is Si: 668 degrees, Ge: 369 degrees. Both θ_D curves show a minimum, 32 percent below the T^3-region value, at $T=40$°K (Si) and $T=22$°K (Ge). The two θ_D curves can be brought to coincidence below the minimum if the two axes (θ_D and T) for Si are reduced by 1.8. The linear term in C_v is not yet understood. It seems doubtful that it is due to the free electron gas, which is responsible for the similar term in metals. Hall measurements indicate that the number of carriers is a hundred times less than is necessary to explain this term.

* Sponsored by Signal Corp Contract W36-039-SC-38151.

O8. Pressure Dependence of Zener Current in Germanium. K. B. MCAFEE, W. SHOCKLEY, AND M. SPARKS, *Bell Telephone Laboratories.*—The dependence of Zener current[1] upon pressure in $p-n$ junctions in germanium has been observed and compared with theory and other measured values of the change of energy gap with pressure, Since the probability of penetration of the energy gap f depends exponentially upon the effective mass m, the field strength E, and the energy gap ϵ_G, terms involving the volume dilation, as well as the pressure dependence of ϵ_G, the dielectric constant κ, and the effective mass m, are involved in the comparison. An independent method has been used to determine the extent to which a change of the dielectric constant with pressure influenced the result. This consists of a measurement of the change in capacity of the $p-n$ junction at a constant reverse bias as pressure is applied. The pressures employed range from 0 to 200 atmospheres. In this region $(d\ \ln i/d\Delta)_V$, the current change per unit current per unit dilation, is about 300. This assumes a value for $d\Delta/dp$ of 1.34×10^{-6}/atmos calculated from measurements of the elastic constants of germanium. The value of $(d\ \ln i/d\Delta)$ is constant for two decades of current as the voltage V is increased, dropping off considerably for higher currents sufficient to produce some heating.

[1] McAfee, Ryder, Shockley, and Sparks, Phys. Rev. **83**, 650 (1951).

O9. Evidence of Hole Traps in Ge Produced by Fast Neutron Bombardment. J. H. CRAWFORD, JR., J. W. CLELAND, K. LARK-HOROVITZ, J. C. PIGG, AND F. W. YOUNG, JR., *Oak Ridge National Laboratory.*—Prior to the work reported here there was no direct experimental evidence of hole traps (donors) being produced in Ge by nucleon bombardment,[1] although their presence might be expected by analogy from the behavior of *P*-type Si whose resistance increases monotonically with bombardment. It has now been shown experimentally that there is a certain limiting hole concentration $(n_h)_{\text{limit}}$ above which fast neutron bombardment of *P*-type Ge causes a decrease in conductivity due to the trapping of conducting holes. $(n_h)_{\text{limit}}$ proves to be temperature dependent. At 55°C $(n_h)_{\text{limit}}\sim5\times10^{17}$ cm^{-3} while at −78°C its value is less than 4×10^{16} cm^{-3}. Several exposures of *P*-type samples with appropriate hole concentrations made at −78°C and 55°C successively during the same bombardment show that the conductivity decreases at the low temperature and increases at the high temperature. These findings are in good qualitative agreement with a model proposed by Lehman and James[2] in which they consider that both electron traps and hole traps associated with bombardment produced defects are introduced in equal concentrations below the middle of the forbidden energy band.

[1] Cleland, Crawford, Lark-Horovitz, Pigg, and Young, Phys. Rev. **83**, 312 (1951).
[2] K. Lark-Horovitz, Appendix II (Lehman and James), International Conference on Semiconductors, Reading, 1950; G. W. Lehman, Phys. Rev. **81**, 321 (1951).

O10. Calculation of the Specific Heat of Ge.* YÜ-CHANG HSIEH, *Purdue University.*—The specific heat of Ge has been calculated from its elastic constants[1] (as measured at B.T.L.).[2] Since the values of the elastic constants satisfy approximately the condition for consideration of first neighbors only, i.e., $4C_{11}(C_{11}-C_{44})=(C_{11}+C_{12})^2$, only the four nearest neighbors are considered in the calculation. 174 frequencies of vibration are calculated and an approximate frequency spectrum is derived. The specific heat calculated agrees with the unpublished experimental date of Parkinson[3] within about 10 percent in the range 20°K to 150°K; below 20°K using discrete frequencies the theoretical values calculated check fairly well with the experimental results of Parkinson[3] and of Keesom and Pearlman,[3] down to 10°K.

* Supported by Signal Corps Contract.
[1] H. M. J. Smith, Trans. Roy. Soc. (London) **241**, 105 (1948).
[2] J. Bardeen and W. Shockley, Phys. Rev. **50**, 72 (1950).
[3] Parkinson, Ph.D. thesis, Oxford, 1948; Keesom and Pearlman, Signal Corps Report (W36-039-SC-32020, August, 1951).

O11. An Automatic Multirange Recording Device for Measuring Varying Potentials. J. C. PIGG, *Oak Ridge National Laboratory.*—In measurements of the changing electrical properties of semiconductors during neutron bombardment in the nuclear reactor, it is desirable to use automatic recording methods whenever possible. A device has been constructed and is currently being used which fulfills the requirements of the semiconductors under consideration. The components are a 0–3-mv 12-point Brown Electronic recorder with a four-deck 12-point selector switch ganged to the Brown input selector switch, a system of limit switches which activate appropriate stepping relays for automatic circuit changes, a system of scale indication, a vibrating reed electrometer for high resistance measurements, and constant current, constant voltage, and variable power supplies. By means of the limit switches and relays proper scale and circuit changes can be made to keep the data within the range of the recorder and provide a linear plot for changes up to twelve orders of magnitude. Each major component is connected to a needle plug terminal board so that any circuit within the range of the available components can be readily employed. By means of the selector switch ganged with the recorder input switch the external circuit can be changed for each point. This instrument is currently being used to measure resistivity of Ge, Si, and Cu_2O during neutron bombardment, and can also be used to measure static characteristics of semiconductor circuit components.

SATURDAY AFTERNOON AT 2:00

Sherman, Grey Room

(F. W. LOOMIS presiding)

General Physics

P1. Development of Ultra Compact, Ultra High Speed Digital Computers, II. DONALD H. JACOBS, MICHAEL MAY, AND SEYMOUR SCHOLNICK, *The Jacobs Instrument Company.*—In continuation of a program[1] of the development of all-electronic, all-parallel digital computers, a second special-purpose machine has been developed and constructed. This computer, called JAINCOMP-B, is an advanced development of the previously described JAINCOMP-A. It is a 24-digit binary machine in which two 24-digit numbers are added in eight microseconds. Inputs come from registers of switches or punch cards and results are displayed on banks of neon lamps. A magnetic core storage system[2] of 2–4-microsecond access time is used. The computer carries out automatically a program of trigonometric ray tracing, and has several alternate programs (paraxial rays, extra-axial rays, etc.). The computer is small ($16\frac{1}{2}\times21\frac{1}{4}\times30$ inches), light (110 lbs), and simple (300 subminiature tubes). Faults can be located very rapidly with a system of signal lights, and faulty circuits can be replaced instantly because all circuitry is constructed on unitized plug-in subassemblies, of which there are 500. The computer is aircooled via a system of internal ducts. A single type of low cost tube is used throughout, and no selection of tubes is required. No high precision components are employed. The machine computes a program of 171 steps in 0.24 sec.

[1] D. H. Jacobs and M. May, Phys. Rev. **82**, 325(A) (1951).
[2] D. H. Jacobs and M. May, Phys. Rev. **83**, 243(A) (1951).

P2. A Stabilized Synchronous Amplifier. R. G. NUCKOLLS AND L. J. RUEGER, *National Bureau of Standards.*—Synchronous or lock-in amplifiers are known[1,2] to suffer from lack of stability, linearity, and, in addition, from shift of both zero and sensitivity with background noise level. A design was needed in the National Bureau of Standards microwave spectroscopy project with the quantitative, stable performance characteristic of well-designed inverse feedbacks amplifiers. A design using two identical stabilized amplifiers has been used 8 months with negligible short or long term shift of both zero and sensitivity. The voltage wave form in one amplifier is the sum of the reference and input signals; the other wave form is the difference. The difference in *average peak* values is selected by two crystal rectifiers and measures the synchronous component of the input. The circuit has a linear dynamic voltage range greater than 60 db, restricted at the low end by noise and circuit asymmetry and at the upper limit by overloading of the particular crystals used. Alternately, the difference of some property other than average peak voltage; such as rms or average power might be selected with equal or superior results.

[1] W. C. Michels and M. L. Curtis, Rev. Sci. Instr. **12**, 444 (1941).
[2] N. A. Schuster, Rev. Sci. Instr. **22**, 254 (1951).

P3. A Critical-Flow Pneumatic Hygrometer. W. A. WILDHACK, T. A. PERLS, AND J. W. HAYES, *National Bureau of Standards.*—The theory of pneumatic instruments based on critical flow[1] has been adapted to a continuous-flow device to measure humidity. For truly critical flow, the mass discharged through a nozzle must be independent of downstream pressure and proportional to upstream pressure. These conditions are only realized at Reynolds numbers greater than 6000 ± 1000. The critical-flow "bridge" incorporates four nozzles, all operating at Reynolds numbers greater than 7000. The nozzles have long expansion cones (2° total angle) and reach critical flow at a pressure ratio of 0.82 ± 0.02. An impedance causing a pressure drop up to 200 mm Hg may be inserted between nozzles without any change in flow. A calcium-sulfate desiccator removes over 99.9 percent of the moisture from one arm of the bridge and the change in mass flow is measured by the difference in absolute pressure at the entrance to the downstream nozzle. The theoretical calibration of the device involves only pressure and temperature measurements and no experimental proportionality factors. This theoretical calibration agrees with measurements made on standard humidity apparatus to within an uncertainty of ±0.5 percent relative humidity.

[1] W. A. Wildhack, Rev. Sci. Instr. **21**, 25 (1950).

P4. Distribution of Potential in an Electrically Excited Excited Nonhomogeneous Medium. LACHLAN GILCHRIST, *University of Toronto.*—Electric and electromagnetic excitation are applied to the Earth's crust, a nonhomogeneous approximately layered medium in order to obtain evidence for the location of inhomogeneities or anomalies, measured potentials are incorporated in a formula which is applicable only to a homogeneous medium. For example, for a steady state

$$V=\frac{i\rho}{2\pi}\left(\frac{1}{a}-\frac{1}{b}-\frac{1}{L-a}+\frac{1}{L-b}\right)$$

is used, since there is no unique formula applicable to a nonhomogeneous medium; L=distance between source and sink; a, b=the distances of the potential probes from the source; i=current; ρ=resistivity. To minimize or eliminate experimental evidence of "spurious" anomalies the following are essentially necessary. 1. The "stake resistances" at the source and at the sink should be equalized. These are dependent largely on bowls of fifty-feet radius adjacent to and including the center of symmetry of the source and sink and may be measured readily. For numerous typical set-ups the values have been calculated. If it is not convenient to equalize the "stake resistances," they should be measured for correctional purposes, in locating "true" anomalies. 2. The centers of symmetry must be located to evaluate L, a and b. This may be done geometrically or analytically if the distribution of potential within the bowls is determined experimentally. Illustrations are presented from field explorations of the locations of anomalies embedded in extensive earth materials from which they differed in average resistivity.

P5. Propagation of Short Radio Waves Well beyond the Horizon. THOMAS J. CARROLL, *National Bureau of Standards.*—For wavelengths shorter than about 6 meters, radio field strengths well beyond the horizon from high power transmitters have been consistently measured to be many orders of magnitude greater than the fields calculated for a so-called "standard" refracting atmosphere, even when conditions of superrefraction in the atmosphere are known not be be present. A very simple calculation of the fields internally reflected by the "standard" troposphere, following the method of Bremmer as used in the troposphere by Feinstein, agrees remarkably well with measurements at 50 Mc and 3300 Mc. The breakdown of "standard refraction" theory is attributed provisionally to the error in the assumption of linearly decreasing index of refraction to indefinitely great heights. If constant unit index is assumed above 10 km, a bilinear model results, which has been extensively treated theoretically by Furry and others. The bilinear model of "standard" refraction explains the reduced attenuation rate of fields at several horizon distances as higher order modes becoming dominant. Theory and experiment are gradually coming into agreement that the formerly predicted high attenuation rates for vhf and microwaves beyond the horizon are quite erroneous.

P6. Electromagnetic Field Measurements in the Plane of a Circular Aperture. ROBERT E. HOUSTON AND ROBERT H. NOBLE, *Michigan State College.*—The short wavelengths of microwaves have been used by Andrews[1] to study the diffraction pattern of circular apertures in a plane conducting screen. His data did not show the expected rise at the edge of the aperture probably because his detector was of necessity not small compared with the wavelength. Bethe[2] has shown that the expression for the field contains a term proportional to $(a^2-r^2)^{-\frac{1}{2}}$, where a is the radius of the circular aperture. This experiment used 600-megacycle radiation and a detector about 1/25 wavelength. Fields were measured in the plane of apertures with diameters ranging from twice to one-fourth wavelength. A rapid rise in field was noted at the edge of each. The aperture with diameter one-half wavelength showed the greatest transmission per unit area.

[1] C. L. Andrews, J. Appl. Phys. **21**, 761 (1950).
[2] H. A. Bethe, Phys. Rev. **66**, 163 (1944).

P7. Velocities of Ionized Air Shocks near Detonating Explosives. J. SAVITT AND R. H. STRESAU, JR., *U. S. Naval Ordnance Laboratory.*—Measurements of shock velocities in the immediate vicinity of small charges of explosives have been made using a vacuum thermocouple type timer.* The ionized air of the shock was used to start and stop the timing circuit when the shock front reached the charged probes. The distances and times involved varied from about 0.025 to about 0.400 inch and from about 0.10 to about 2.00 microseconds. The air shocks were produced by the detonation of various samples of highly confined primary and high explosives varying in weight up to about one gram and in loading density up to about 95 percent of crystal density. The air shock velocity was found to be dependent upon the distance from the detonation, the composition of the explosive, its weight, and its geometry; but independent of the loading density. Some of the probe problems will be discussed and some of the results of the measurements of ionized air shock velocities presented.

* R. H. Stresau, Phys. Rev. **76**, 880 (1949).

P8. Synchronized Rotating Mirror System.* RICHARD G. FOWLER AND ROBERT J. LEE, *University of Oklahoma.*—A synchronized rotating mirror system has been constructed as an improved means of observing previously described phenomena.[1] These phenomena involve the appearance of moving luminosity in a side tube joined at right angles to a regular discharge tube. Rotating mirror investigations of this luminosity were previously conducted with a system depending on chance for photographic register. The new mirror system is photoelectrically synchronized to record each discharge of the tube. The system consists of a rotating concave mirror, and an infrared projector and photocell circuit which trip a thyratron, thus discharging a condenser through a relay to close a vacuum switch and fire the tube just as the mirror is in axial position. To eliminate aberration, the arrangement requires that the image fall on a film only 6 cm wide at a distance of 115 cm with 30-rps mirror speed. Excellent reproducibility of register and mirrorgram detail has been obtained.

* Project supported by the ONR.
[1] Fowler, Goldstein, and Clotfelter, Phys. Rev. **82**, 879 (1951).

Post-Deadline Papers, If Any

SATURDAY AFTERNOON AT 2:00

Sherman, Louis XVI Room

(ALLEN C. G. MITCHELL presiding)

Beta-Decay, Nuclear Isomerism, etc.

Q1. Empirical Analysis of Nuclear Shell Effects in β-Energetics.[1] C. D. CORYELL, R. A. BRIGHTSEN,[2] AND A. C. PAPPAS,[3] *Massachusetts Institute of Technology.*—An analysis of available decay data for nuclides of odd A ($A>50$) indicates that the total energy E_d for β-decay or electron capture is given reasonably satisfactorily by the Weizsäcker-Bohr-

Wheeler term $B_A[|Z-Z_A|-0.5]$ in any region not affected by neutron or proton shell edges. The reduction in neutron or proton binding energies associated with the crossing of a shell edge leads to displacements ΔZ_A in the Z_A curve, upward for neutron crossings and downward for proton crossings. Empirically identified shifts in the well-defined Z_A curves indicate the following values $|B_A\Delta Z_A|$ in Mev for the discontinuities in neutron and proton binding energies at the shell populations of 28, 50, 82, and 126: 1.0 and 1.2, 2.2 and 1.7, 1.7 and 1.3, and 1.1 (neutrons only). This procedure has been used to establish limits on the energy effects of possible subshells at other nucleon numbers such as 34, 40, 64, and 100. It can also be extended to give better interpolations among atomic masses.

[1] Supported in part by the AEC.
[2] Presently at Westinghouse Atomic Power Division, Pittsburgh.
[3] Fellow of the Norwegian Council of Scientific and Industrial Research.

Q2. Atomic Binding Energy Considerations in Negative Beta-Decay.* H. M. SCHWARTZ, *University of Arkansas.*—The extreme low end of negative beta-spectra is sensitive to the mode of utilization of the excess atomic binding energy liberated in the increase of nuclear charge during the decay process. In the case of the heavy nuclides, a measurable cutoff is to be expected in the lower end of the spectrum corresponding to this excess binding energy, if this energy is carried away by the beta-particle *subsequent* to its appearance in the nuclear decay process.[2] Such a cutoff does not, however, follow from an application of conventional time-dependent perturbation theory to the combined system of nucleus, lepton field, and atomic electrons, subject to Fermi and coulomb couplings. There seems, as yet, to exist no clear-cut experimental evidence regarding this question, although it is hoped that pertinent data from proportional counter measurements now in progress will be available in the near future.

[1] This work is supported in part by the AEC.
[2] Edwards, Damon, and Schwartz, Phys. Rev. **82**, 333(A) (1951). The following additional reference has come to our attention recently: L. Goldstein, J. phys. et radium **8**, 235 and 316 (1937).

Q3. The *K*-Auger Yield for Ba. C. D. BROYLES* AND S. K. HAYNES, *Vanderbilt University.*—Measurements of the Auger yield for elements of $Z>40$ are few and tend on the whole to give larger yields than predicted by the approximate theory of Massey and Burhop. We have made a careful comparison in a lens spectrometer of the intensity of the K-Auger lines with the intensity of the K-conversion line from the isomeric state of Ba^{137}. The source ($\sim$.01 mg cm^{-2}) was vacuum evaporated onto a copper on Formvar film of about .075 mg cm^{-2} total weight. The counter window was less than .018 mg cm^{-2} Nylon supported on Lectromesh with a transmission limit of about 3 kev. Because the forbidden Kurie plot curved sharply upward below 40 kev, the base line under the Auger peaks was slightly uncertain. A preliminary minimum value for the Auger yield of Ba is 0.129 ± 0.01 compared to a value of 0.15 predicted by Massey and Burhop.[1] The origin of the excess electrons below 40 kev will be discussed.

* AEC Predoctoral Fellow.
[1] H. S. S. Massey and E. H. S. Burhop, Proc. Roy. Soc. (London) **153**, 681 (1936).

Q4. Proposed Methods for Determining *K*-Capture Partial Lifetimes.* A. J. SAUR AND H. M. SCHWARTZ, *University of Arkansas.*—Because of the peculiar difficulties in obtaining precise measurements, only a few reliable values for K-capture partial lifetimes are known. These measurements have been made by ingenious methods applicable to only a small number of nuclides. From information obtained at this and other laboratories, we have designed a proportional counter arrangement for such studies which should be applicable to a fairly large family of nuclides, as determined by a careful study of known physical and chemical properties of such nuclides. The proportional counter is so designed as to resolve with relatively high accuracy pulses due to Auger electrons emitted in K-capture from the weaker pulses due to the less ionizing X, unconverted gamma, and hard positron radiation. Limits to the precision obtainable are imposed by the as yet insufficiently studied surface effects in proportional counters as well as by inadequate present knowledge of K-shell fluorescence yields for higher Z elements. Two other methods, involving, respectively, cloud-chamber and hot-atom chemistry techniques, will be discussed.

* This work is supported in part by the AEC.

Q5. Beta-Spectra of Ce^{144} and Pr^{144}. FRED T. PORTER AND C. SHARP COOK, *Washington University.**—Electron spectra from thin sources of chemically purified Ce^{144} have been observed in the 180° uniform field magnetic spectrometer. Ce^{144} (275-day) decays to Pr^{144} (17-min) which decays to stable Nd^{144}. The highest energy beta-group, which is believed to be associated with the decay of Pr^{144}, has an end-point energy, according to the F-K plot, of 2.97 ± 0.02 Mev. The F-K plot exhibits a straight line back to approximately 450 kev where a small deviation occurs. A large deviation occurs at about 310 kev. The latter groups can be fitted into a decay scheme consistent with observed gamma-radiations attributed to Ce^{144}. From the linearity of the high energy F-K plot and the absence of gamma-radiation of sufficient intensity to follow all disintegrations of Pr^{144}, it appears that the most probable mode of decay of Pr^{144} is by beta-emission to the ground state of Nd^{144}.

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

Q6. Relative Internal Conversion in the *L* Subshells.* J. W. MIHELICH AND E. L. CHURCH, *Brookhaven National Laboratory.*—An experimental survey is being made of the relative intensity of L_I, L_{II}, and L_{III} conversion lines of certain low energy γ-rays originating in nuclei of medium atomic number. Data have been obtained for the following multipole orders: $M1$, $M1+E2$, $E2$, and $M4$. Semicircular photographic spectrographs are being employed. The results can be summarized as follows. Multipole order assignments are taken from Goldhaber and Sunyar.[1] (1) $M1$ transitions are L converted in the L_I shell predominantly. This is in accord with the observation that experimental K/L_{total} ratios for magnetic dipole transitions are not in disagreement with the ratio of the following theoretical values: the K-shell conversion coefficients of Reitz[2] and the L_I shell coefficients of Gellman, Griffith, and Stanley.[3] (2) $E2$ transitions are L converted in the L_{II} and L_{III} shells primarily, L_I conversion being appreciably less. (3) It seems that relative mixtures of $M1$ and $E2$ may be determinable from L_{II}/L_I or L_{III}/L_I ratios. (4) $M4$ transitions are L converted in primarily the L_I and L_{III} shells. This trend with increasing magnetic multipole order is in agreement with the approximate theory of Tralli and Lowen.[4]

* Research performed under auspices of the AEC.
[1] M. Goldhaber and A. W. Sunyar, Phys. Rev. **83**, 906 (1951).
[2] J. R. Reitz, Phys. Rev. **77**, 10 (1950).
[3] Gellman, Griffith, and Stanley, Phys. Rev. **80**, 866 (1950).
[4] N. Tralli and I. S. Lowen, Phys. Rev. **76**, 1541 (1949).

Q7. 514-kev Energy Level of Rubidium 85. W. S. EMMERICH AND J. D. KURBATOV, *Ohio State University.*—The deexcitation of the 514 ± 3-kev energy level appearing in orbital electron capture of strontium 85, half-life 65 days, has been studied.[1] A permanent magnet spectrograph, a lens spectrometer, and coincidence absorption techniques were used. The internal conversion of the gamma-ray was found to be 7×10^{-3} and the K to L conversion ratio is 13. Coincidences could not be detected between x-rays and gamma-rays. This shows that the 514-kev excitation level in Rb is metastable. A search was made for radiation corresponding in energy to

levels known to exist from the disintegration of Kr 85. In the region from 120 to 200 kev such radiation is absent to the limit of 0.75 percent of the total activity.[2]

[1] M. Ter-Pogossian and F. T. Porter, Phys. Rev. **81**, 1057 (1951).
[2] L. Cheng and J. D. Kurbatov, Phys. Rev. **79**, 237 (1950).

Q8. Isomerism of Sr^{85}. A. W. SUNYAR, J. W. MIHELICH, G. SCHARFF-GOLDHABER, M. DEUTSCH,* AND M. GOLDHABER, *Brookhaven National Laboratory.*†—Sr^{85m} (70 min) decays via a two-step isomeric transition and a cross-over transition to the ground state, and by K capture (~16 percent) to a 150-kev excited state of Rb^{85}. The lifetime determining step is a highly converted $E3$ transition of ~6 kev which is followed by an $M1$ transition of ~220 kev. The $M4$ cross-over transition of ~226 kev has been observed in a 180° magnetic spectrograph. The conversion coefficient for the 220-kev transition is obtained by comparison of gamma-ray and conversion electron intensities for the 150-kev and 220-kev transitions. Conversion electrons from the 6-kev transition have been observed in a flow proportional counter and an ion chamber. The main isomeric transition proceeds as follows:

$$p\ 1/2 \xrightarrow{6\text{ kev}} 7/2+ \xrightarrow{220\text{ kev}} g\ 9/2.$$

The 7/2+ state involves coupling of 7 odd neutrons in g 9/2 orbits as previously noted for several isomeric transitions. The intensities of the $M4$ cross-over transition agrees with that expected from the semi-empirical formula of Goldhaber and Sunyar.[1] The ground state of Sr^{85} (65d) decays by K-capture to an excited state of 510 kev, for which a half-life of (0.9±0.2) μsec has been established. A decay scheme consistent with shell theoretical predictions and experimental evidence for the decay of Kr^{85}, Rb^{85}, and Sr^{85} will be discussed.

* Permanent address: Massachusetts Institute of Technology.
† Research performed under the auspices of the AEC.
[1] M. Goldhaber and A. W. Sunyar, Phys. Rev. **83**, 906 (1951).

Q9. Disintegration Scheme of Lu^{176m}. G. SCHARFF-GOLDHABER, E. DER MATEOSIAN, AND J. W. MIHELICH, *Brookhaven National Laboratory.*—Lu^{176m} is known[1] to decay with a half-life of 3.7 hr, emitting beta-particles of 1.0- to 1.2-Mev maximum energy, whereas the ground state of Lu^{176} has a beta-spectrum with a maximum energy of 0.2 to 0.4 Mev and a half-life of 2.4×10^{10} yr. A search was therefore made, with a sensitive scintillation spectrometer, for a γ-ray of 0.6–1 Mev due to an isomeric transition of Lu^{176m}. No such γ-ray was observed, indicating that the spin difference between ground state and excited state is at least 5. However, a strongly converted (89.0±0.5) kev γ-ray was found in the 3.7-hr Lu isomer following the β-ray (1.1 Mev) with <1-μsec delay, with a K/L ratio of 0.10±0.06, indicating an $E2$ transition. The spin and parity of the first excited state in Hf^{176} are thus 2+, in agreement with a rule for even-even nuclei recently pointed out by Goldhaber and Sunyar.[2] Beta-rays of 1.2 Mev going directly to the ground state of Hf^{176} were also found. Spin and parity of Lu^{176m} are assigned as 1+.

[1] K. Way *et al.*, Natl. Bur. Standards (U. S.) Circ. 499.
[2] M. Goldhaber and A. W. Sunyar, Phys. Rev. **83**, 906 (1951).

Q10. The Radioactive Decay of Te^{125m}. P. AXEL AND J. C. BOWE,* *University of Illinois.*†—The branching ratios for each of the two transitions in Te^{125m} were determined by experiments which used a thin-lens beta-ray spectrometer, a NaI crystal scintillation spectrometer, and two proportional counters in coincidence. The unconverted 110-kev gamma-ray from the first transition was observed and its K conversion coefficient was measured as 160±20. For the second transition, the following branching was obtained: K conversion = 0.80 ±0.06, L conversion = 0.11±0.03, M conversion = 0.02, and the unconverted gamma-ray = 0.07±0.02. These data are consistent with the suggested level assignment[1] of $_{1/2}$, $d_{3/2}$, and $_{11/2}$. They further indicate that the second transition is predominantly magnetic dipole. A comparison of these results with existent theoretical internal conversion calculations will be given.

* Now at Argonne National Laboratory, Chicago, Illinois.
† Assisted by the joint program of the ONR and AEC.
[1] J. C. Bowe and G. S. Goldhaber, Phys. Rev. **76**, 437 (1949).

Q11. The Second Transition in the Decay of Sn^{119m}. J. C. BOWE* AND P. AXEL, *University of Illinois.*†—The photons from the second transition of the 250-day isomer[1] of Sn^{119} were detected in coincidence with x-rays from the first transition by using two proportional counters. These photons have an energy of 23.8±0.6 kev. Since In x-rays (24.2 kev) and Sn x-rays (25.2 kev) were present, the gamma-rays could be distinguished only by coincidence measurements. The fraction of the unconverted gamma-rays was found to be 0.13 ±0.03. This corresponds to a total conversion of 7.3±1.7. The experimental evidence favors an assignment of magnetic dipole to this transition.

* Now at Argonne National Laboratory, Chicago, Illinois.
† Assisted by joint program of the ONR and AEC.
[1] J. W. Mihelich and R. D. Hill, Phys. Rev. **79**, 781 (1950).

Q12. The Decay of Rh^{106}. DAVID E. ALBURGER, *Brookhaven National Laboratory.**—$Ru^{106}-Rh^{106}$ beta-rays with end points 3.53±0.01 Mev (68 percent), 3.1±0.1 Mev (11 percent), 2.44±0.07 Mev (12 percent), and 2.0±0.1 Mev (3 percent) have been observed using a lens spectrometer. Gamma-rays are also present with energies of 0.513, 0.624, 0.87, 1.045, and 1.55 Mev and relative intensities of 1:0.53: 0.03:0.08:0.025, respectively, as measured by photoelectric conversion. There is evidence for a gamma of 2.9 Mev. The 0.513- and 0.624-Mev lines are internally converted with K intensities of 7.5×10^{-4} and 2.3×10^{-4} relative to total beta-radiation. At 1.6 percent resolution the 0.513-Mev transition K and L conversion lines are separated and have a ratio of 7.8±1. Using the recent analysis of K/L ratios by Goldhaber and Sunyar, one can conclude that this transition is an electric quadrupole; from relative conversion intensity the 0.624-Mev line must also be $E2$. The results are consistent with beta-decay to states in Pd^{106} at zero, 0.513, 1.137, and 1.55 Mev. The 0.87- and possible 2.9-Mev gamma-rays and excess beta-rays are apparently associated with weakly excited higher states. From this scheme the K-conversion coefficients of the 0.513- and 0.624-Mev gammas are $(3.5\pm1)\times10^{-3}$ and $(2.1\pm1)\times10^{-3}$, both consistent with $E2$.

* Under contract with the AEC.

Q13. A Clarification of the Radioactivity of Nd^{151} and Pm^{151}. W. C. RUTLEDGE,* J. M. CORK,† AND S. B. BURSON, *Argonne National Laboratory.*‡—Enriched Nd^{150} was activated in the Argonne reactor. The internal conversion electrons and photoelectrons from a lead radiator were investigated in a permanent magnet-type beta-spectrograph. Gamma-rays of 85.4 and 117.1 kev, decaying with a half-life of 12 min, show work-function differences of prometheum. Apparently they follow emission of the 1.93-Mev beta-ray, which is thus assigned to Nd^{151}. Absorption measurements show prometheum K-x-rays and another gamma-ray of 895 kev. This 12-min activity proves to be the parent of a 27.5-hr beta-ray of 1.1 Mev in Pm^{151}. (This is the usual case where the half-lives of members of a chain with odd mass numbers increase successively down the chain.) Associated gamma-rays of 64.7, 65.8, 69.6, 99.9, 116.2, 105.0 (or 144.0), 163.1, 168.0, 177.0, 208.3, 231.9, 239.9, 275.2, and 340.1 kev are characterized by samarium work function differences. Absorption measurements also show a weak 615-kev gamma-ray. These data and coincidence measurements make it possible to propose a decay scheme.

* Phoenix Project Fellow, University of Michigan.
† University of Michigan.
‡ Supported in part by the joint program of the ONR and AEC.

Q14. Mass Designation of the 51.5 Min-Tc Isomer.* HEINRICH A. MEDICUS AND HARRY T. EASTERDAY, *University of California.*—By proton bombardment of molybdenum of natural isotopic composition about a dozen Tc activities are produced which, with a few exceptions, could all be ascribed to specific isotopes. One exception is the Tc isomer of 51.5-min half-life and 34.4-kev transition energy[1] which is relatively difficult to detect due to its low energy and because it is masked by the 52.5-min positron emitter, Tc^{94}. By bombardment of enriched Mo isotopes with protons of 9.5-Mev energy in the 60-in. cyclotron and then by using a lens spectrometer to compare the intensity of the L-line of the isomer with characteristic conversion lines of the known isotopes, it could be proved that this isomer belongs to Tc^{96} whose ground state has a half-life of 104 hours. This isomer was also produced by 4-Mev protons from the Berkeley electrostatic generator on natural molybdenum. This also confirms the previous results[1] that the isomer is not connected with the positron emitter Tc^{94} since the (p, n) threshold to produce the latter activity requires a proton energy of 5.1 Mev.

* This work was supported by the AEC.
[1] Medicus, Preiswerk, and Scherrer, Helv. Phys. Acta **23**, 299 (1950).

SATURDAY AFTERNOON AT 2:00

Sherman, West Room

(H. MARGENAU presiding)

Joint Symposium of the American Physical Society and the Philosophy of Science Association

R1. Inductive Logic and Science. R. CARNAP, *University of Chicago.* (45 min.)
R2. Philosophical Interpretations of Modern Physics. P. FRANK, *Harvard University.* (45 min.)
R3. Quantum Measurement as an Amplifying Process. W. M. ELSASSER, *University of Utah.* (45 min.)

SUPPLEMENTARY PROGRAMME

SP1. Phenomenological Theory of Lamb Shift.* FREDERIK J. BELINFANTE, *Purdue University.*—Ignoring self-interactions one can explain the Lamb shift and anomalous magnetic moments of electrons and protons by introducing appropriate interactions between these particles and photons. Using methods of gauge-independent quantum electrodynamics we take in the generalized Schrödinger equation for these particles the interaction operator $W=\mathbf{D}_{\mathrm{II}}^2/8\pi-\mathbf{D}_{\mathrm{II}}\cdot\mathbf{P}-\mathbf{D}_{\mathrm{II}}\cdot\mathfrak{E}/4\pi-\mathfrak{E}\cdot\mathbf{P}+2\pi\mathbf{P}^2-\mathfrak{A}\cdot\mathbf{j}-\mathfrak{B}\cdot\mathbf{M}+\frac{1}{2}C(\mathbf{j}^2-\rho^2)$, where $\mathfrak{E}$, $\mathfrak{B}$ = transverse electromagnetic field; $\mathfrak{A}(\mathbf{x},t)\equiv\int d^3\mathbf{x}'\,\mathrm{curl}'\mathfrak{B}(\mathbf{x}',t)/4\pi r$; $\mathbf{D}_{\mathrm{II}}(\mathbf{x},t)\equiv-\nabla\int d^3\mathbf{x}'\rho(\mathbf{x}',t)/r$; $\rho\equiv e(:\psi_{\mathrm{P}}^\dagger\psi_{\mathrm{P}}:-:\psi_\epsilon^\dagger\psi_\epsilon:)$; $\mathbf{j}\equiv e(:\psi_{\mathrm{P}}^\dagger\boldsymbol{\alpha}\psi_{\mathrm{P}}:-:\psi_\epsilon^\dagger\boldsymbol{\alpha}\psi_\epsilon:)$; $\mathbf{P}\equiv f_{\mathrm{P}}:\psi_{\mathrm{P}}^\dagger\boldsymbol{\gamma}\psi_{\mathrm{P}}:+f_\epsilon:\psi_\epsilon^\dagger\boldsymbol{\gamma}\psi_\epsilon:$; $\mathbf{M}\equiv f_{\mathrm{P}}:\psi_{\mathrm{P}}^\dagger\beta\boldsymbol{\sigma}\psi_{\mathrm{P}}:+f_\epsilon:\psi_\epsilon^\dagger\beta\boldsymbol{\sigma}\psi_\epsilon:$; $\boldsymbol{\gamma}=-i\beta\boldsymbol{\alpha}$. The integrability of $i\hbar\delta\Psi[\sigma]=\int d^3\mathbf{x}'\delta t\times(\mathbf{x}')W(\mathbf{x}',\sigma)\Psi[\sigma]$ is proved for flat σ. We put $\mathbf{D}\equiv\mathfrak{E}+\mathbf{D}_{\mathrm{II}}$, $\mathbf{H}\equiv\mathfrak{B}-4\pi\mathbf{M}$, $\mathfrak{E}\equiv\mathbf{D}-4\pi\mathbf{P}$. In Heisenberg representation then $\mathbf{D}$, $\mathbf{H}$ and $\mathbf{E}$, $\mathfrak{B}$ are tensors satisfying with ρ, $\mathbf{j}$ the phenomenological maxwell equations. The energy density is $(\mathbf{E}^2+\mathfrak{B}^2)/8\pi+\frac{1}{2}C(\mathbf{j}^2-\rho^2)+\Sigma_{\epsilon,\mathrm{P}}\Re\{\psi^\dagger(mc^2\beta-ihc\boldsymbol{\alpha}\cdot\nabla)\psi\}-\mathfrak{A}\cdot\mathbf{j}-\mathfrak{B}\cdot\mathbf{M}$ and the momentum density $=\mathbf{E}\times\mathfrak{B}/4\pi c+\Sigma_{\epsilon,\mathrm{P}}\Re\{\psi^\dagger(\hbar/i)\nabla\psi+\frac{1}{4}\times\mathrm{curl}(\psi^\dagger\hbar\boldsymbol{\sigma}\psi)\}-\rho\mathfrak{A}/c-\mathfrak{B}\times\mathbf{P}/c$. The experimentally observed magnetic moments are obtained by choosing $f_{\mathrm{P}}=+0.000976\mu_B$ and $f_\epsilon=-0.00119\mu_B$, and a Lamb shift $\delta E_{2s\frac{1}{2}}-\delta E_{2p\frac{1}{2}}=1062$ Mc is obtained by choosing $C=1.062\times10^{-22}$ cm^2. This Lamb shift then depends on atomic number and quantum numbers by $\delta E_{nlj}=\{|f_\epsilon/\mu_B|(-1)^{l-j+\frac{1}{2}}(j+\frac{1}{2})^{-1}(l+\frac{1}{2})^{-1}+(2C/\pi)(m_\epsilon c/\hbar)^2\times\delta_{l,0}\}\times Z^4\alpha^2\,\mathrm{Ry}/n^3$, in good agreement with Bethe's formula.

* To be given at the end of Session I if time permits.

SP2. Clustering of Ions.*† HENRY MARGENAU AND STANLEY BLOOM, *Yale University.*—Kinetic theory is employed in investigating the extent to which polarizable molecules attach themselves to slowly moving ions in a gas, the underlying picture being that commonly used in deriving the barometer formula, i.e., the aggregation of molecules in a constant field of force. An intermolecular potential energy of the form $-\mathrm{K}R^{-4}$ for $r\geqslant r_0$ but ∞ for $r\leqslant r_0$, leads to a very great tendency for cluster formation of r_0 is taken to be the (Van der Waals) distance of closest approach. This potential, however, packs most of the clustered molecules into the sharp crevasse near r_0 and therefore falsifies the result. When the cusp is removed and a more adequate potential of the form $cR^{-12}-\mathrm{K}R^{-4}$ is chosen, the tendency to aggregate is seen to vanish, except in the case of Li^+, which remains a strong clustering agent. Our analysis treats the neutral molecules as points and therefore ignores all steric effects. These would reduce clustering still further and are therefore uninteresting except in unusual cases.

* Supported by the ONR.
† To be given at the end of Session B if time permits.

Author Index to Papers Presented at the Chicago Meeting