Proceedings of the American Physical Society

MINUTES OF THE MEETING AT WASHINGTON, APRIL 27–29, 1950

THE 299th meeting of the American Physical Society, being the 1950 Spring Meeting, was held at Washington, D. C., on Thursday, Friday, and Saturday, April 27, 28, and 29, 1950. Most of our recent meetings have been unique in one important feature or another; this one comprised the greatest number of contributed (ten-minute) papers on record, amounting to 273. Since—more through accident than through design—the number of invited papers was unusually small and there were no symposia, the total number of papers did not set a new record, and the available halls were ample for our meetings. We are grateful to the Local Committee, headed as in recent previous years by Claire Marton and Hugh Odishaw, who did an immense amount of work for our benefit and did it very well; to the National Bureau of Standards for intervening with various Departments of Government to obtain the privilege of using their lecture halls, to these Departments themselves, and to the Bureau for welcoming us to its excellent East Building Lecture Room; to George Washington University for lending us its Lisner Auditorium, and to the National Academy of Sciences for the repeated favor of its own Auditorium. The only drawback to these arrangements is the wide dispersion of the halls. It will be interesting to our members to be told that owing to the initiative of Mrs. Marton and Mr. Odishaw, we expect to be able to confine next year's meeting to the halls of a prominent hotel and those of the National Bureau of Standards. The registration this year was about fifteen hundred. It is taken for granted that many of those in attendance failed to register; but even with all reasonable allowance for this factor it appears that our Washington meetings do not match our New York meetings in respect to total attendance.

The twelve invited papers were given by Felix Bloch (T1), J. W. M. DuMond (H1), Maurice Goldhaber (Y1), J. A. Hipple (A3), R. B. Holt (A1), Hans Kopfermann (I1), D. H. Menzel (T3), J. R. Pierce (A4), Grote Reber (T2), William Shockley (J14), H. S. Taylor (A2), and Herbert York (F12). The letters and numbers after these names indicate where in the following pages the titles of these papers will be found; for, as already twice announced in the *Bulletin*, the pages of the *Bulletin* which carry the abstracts and the intervening material are now and henceforth will be reproduced in *The Physical Review* without the least alteration, except for the renumbering of the pages. Preceding these pages are printed the "errata" which the contributors of abstracts have sent to the American Institute of Physics since the *Bulletin* appeared.

The banquet of the Society was held on the Friday evening in the Grand Ballroom of the Mayflower Hotel, and was adorned by after-dinner speeches by W. V. Houston and H. D. Smyth.

The Council met on the Wednesday preceding the meeting of the Society, and selected to Membership one hundred and five candidates whose names appear hereinafter. It will be of interest to our members to learn that the work of preparing a thirty-year Author and Subject Index of *The Physical Review* is well under way. Since the Index is to extend through 1950, it can scarcely be published before the autumn of 1951.

According to reports reaching the office of the Society, we have lost through death D. Coster (Groningen, Holland).

The Nominating Committee met on the Thursday afternoon, and reported that the following Fellows of the Society will be candidates for office in the election to be held next January: C. C. Lauritsen for President, J. H. Van Vleck for Vice-President, K. K. Darrow for Secretary, G. B. Pegram for Treasurer; R. F. Bacher, J. B. Fisk, E. M. Purcell, and H. K. Schilling for Councillor (four-year term, two vacancies to be filled); Maurice Goldhaber, Robert Serber, and C. H. Townes for membership in the Board of Editors (three-year term, three vacancies to be filled).

Elected to Membership: Carl D. Baumann, Raymond E. Benenson, John P. Benkard, Kurt Berman, William M. Boggs, Francis G. Boyle, Pierce A. Brennan, Karl W. Brockman, Jr., Bjorn Bruno, Nestor Cadorette, William F. Cartwright, Joses Jen Lieh Chen, Calvin M. Class, Julius Cohen, George E. Comstock, III, E. N. Dacus, Alcides R. Da Silva, Raymond L. Dickeman, John E. Dougherty, Joseph Dresner, Leonard Norman Eselson, Frederick C. Essig, John J. Floyd, Michael J. Forster, Meyer Garber, Robert W. Gelinas, Desmond A. George, James F. Goff, C. Herbert Grauling, Jr., Thomas C. Hall, Jr., John C. Hubbs, Leslie E. Johnson, Geoffrey Jones, Malvin H. Kalos, Harvey Kaplan, Robert W. Keyes, Charles H. Klane, Jack Kliger, Nobuo J. Koda, John W. Kunstadter, Wilbur Lakin, Erkki A. Laurila, Herbert N. Leifer, John L. Levy, C. H. Long, Stefan Machlup, Jose M. Malpica, John A. McCarthy, T. King McCubbin, Jr., Robert E. McDonald, Francis D. McDonough, George F. Mechlin, Clarence R. Mehl, William H. Metten, Richard A. Montgomery, George J. Moshos, H. Motz, Michael J. Neumann, Kaworu C. Nomura, James O'Day, Paride A. Ombrellaro, Wilfred E. Osberg, Jr., William Oshinsky, Paul G. Pallmer, Jr., Charles S. Peet, Martin L.

Perl, Robert H. Phillips, Roy Pietsch, George Edgar Reis, Howard Reiss, Fred L. Ribe, David C. Rich, Carl J. Rigney, Alfred C. Robinson, William G. V. Rosser, Kenneth Rubin, Donald H. Rusling, Stephen F. Samojeden, John E. Setzko, Henry Shenker, Henry B. Silsbee, Charles H. Skeen, Beatrice Anne Slater, John K. Sloatman, Jr., Curtiss A. Smith, William Spindel, D. Arthur Spohr, Henry L. Stadler, William E. Stein, Richard K. Steinberg, Robert M. Sugarman, Robert G. Sutherland, Nils Svartholm, Robert K. Swank, Chuan Tseng Tai, Theodorus A. M. Van Kleef, Henry Viervoll, Charles F. Wahlig, John C. Wahr, Gordon W. Wares, Gabriel Weinreich, Roger P. Wellinger, Norman M. Wolcott, Roger D. Woods, Miss Tosiko Yuasa, and George W. Ziegler, Jr.

With immeasurable regret we announce that John T. Tate, most wise, able, and diligent servitor of the Society for twenty-four years in the office of Managing Editor, departed this life on May 27, 1950.

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

Errata Pertaining to Papers C1, D11, I3, I8, J1, J8, M6, M7, O4, O7, P2, P3, R8, V2, W10, W13, and Y6

C1, by Leitner and Spence. The word "approximate" in the sixth line should read "appropriate."

D11, by Sumner Mayburg. The quantity $\partial \ln\epsilon/\partial p$ for KCl should be -1.05×10^{-5} bar^{-1} instead of -1.03×10^{-5} bar^{-1}.

I3, by O. H. Arroe. Beginning should read: "In hyperfine structure studies with separated isotopes^{++} of Mo^{95} and Mo^{97}, certain lines, including $4d^5\,5s\,{}^7S_3-4d^5\,5p\,{}^7P_{2\,3\,4}$ and $4d^5\,5s\,{}^5S_2-4d^5\,5p\,{}^5P_{1\,2\,3}$, show clearly. . . ."

I8, by William M. Conn. Line 7: Change "exposition" to "explosion." Add at end of abstract: Assisted by the ONR.

J1, by W. F. G. Swann. Line 5: The expression $e^{-\alpha x}$ should read $e^{-\alpha t}$. Lines 13 and 14: Delete the words: "and that the time constant $1/\alpha$ is greater than RC." Line 18: "τ_2 with a week" should read "τ_2 with two weeks."

J8, by H. Ekstein and T. Gilbert. Line 14: Replace $t_n = t_{d/6P}$ by $t_n = t_d/P$.

M6, by R. E. Marshak and A. S. Wightman. Line 2: "A. S. Whitman" should read "A. S. Wightman." Lines 13 and 14: $g^2/\hbar c$ should be equated to $0.25^{+0.2}_{-0.1}$ instead of $0.55^{+0.3}_{-0.1}$, and $g^2/\hbar c$ should be equated to $0.03^{+0.02}_{-0.01}$ instead of $0.07^{+0.04}_{-0.01}$.

M7, by Stephen Tamor. The next to last sentence should read: "For pseudoscalar mesons the radiative and non-radiative absorption probabilities are comparable."

O4, by John Sheridan and Walter Gordy. The moments of inertia should be 537.417×10^{-40} g/cm^2 and 541.121×10^{-40} g/cm^2.

O7, by Quitman Williams and Walter Gordy, "$678._1\times10^{-40}$ g/cm^2 and 683.7×10^{-40} g/cm^2" should read "672.5×10^{-40} g/cm^2 and 689.4×10^{-40} g/cm^2.

P2, by J. Brossel, P. Sagalyn, and F. Bitter. Footnotes should be added at the end of the abstract as follows: (a) M. H. L. Pryce, Phys. Rev. **77**, 136 (1950), and (b) J. Brossel and A. Kastler, Comptes Rendus **229**, 1213, (1949). These footnotes were present in the manuscript submitted by the authors but were removed by the editor to reduce the abstract to the stipulated length.

P3, by T. L. Collins. The value quoted for the magnetic moment of Sb^{121} is incorrect. Subsequently to submission of the abstract, the observed signal was identified as due to Cu^{63} in the metallic copper of the detector coil. The resonance due to Sb^{121} has been observed in agreement with Proctor (private communication).

R8, by A. H. Van Tuyl. Line 11: $\epsilon(1-\sigma)$ in place of ϵ. Line 12: $\epsilon(1-\sigma)^2$ in place of $\epsilon(1-\sigma)$. Line 13: $\epsilon(1-\sigma)^{5/2}$ in place of $\epsilon(1-\sigma)^2$. Line 19: $\epsilon(1-\sigma)$, $\epsilon(1-\sigma)^2$ in place of ϵ, $\epsilon(1-\sigma)$. Line 20: $\epsilon(1-\sigma)^{5/2}$ in place of $\epsilon(1-\sigma)^2$.

V2, by Joseph A. Bruner and Lawrence M. Langer. The first names of both authors were omitted from the abstract.

W10, by James Terrell. In line four, the reaction is $Be^9(\alpha n,\gamma)C^{12}$.

W13, by W. W. Buechner and D. M. Van Patter. Q-value, line 6, read: 9.232. Q-values, line 7, read: 7.091; 4.775; 2.480; 2.430; 1.935; 0.667; and 0.311 Mev. Q-value, line 15, read: 2.430 Mev. Q-value, line 16, read: 2.480 Mev.

Y6, by Robert Stump and Sherman Frankel. The title should read "$\beta-\gamma$-Angular Correlation Measurements." In footnote 2 "Carwin" should read "Garwin."

PROGRAMME

THURSDAY MORNING AT 10:00

Lisner Auditorium

(J. E. MAYER presiding)

Invited Papers

A1. High-speed Spectroscopic and Electron-Density Measurements on Gas-Discharge Plasmas. R. B. HOLT, *Harvard University.* (40 min.)

A2. Adsorption, Catalysis, and the Physics of Surfaces. H. S. TAYLOR, *Princeton University.* (40 min.)

A3. Recent Developments in Precision Mass-Spectroscopy and the Present Status of the Method of Magnetic Resonance. J. A. HIPPLE, *National Bureau of Standards.* (30 min.)

A4. Physical Aspects of Postwar Microwave Amplifiers. J. R. PIERCE, *Bell Telephone Laboratories.* (35 min.)

THURSDAY MORNING AT 10:00

Departmental Auditorium

(L. R. HAFSTAD presiding)

Fission; Nuclear Masses; Miscellany in Nuclear Physics

B1. Fission of Liquid Drop Nuclear Model. DAVID L. HILL, *Vanderbilt University.*—The computed trajectory of the liquid drop model undergoing fission will be discussed. Particular attention will be paid to an oscillatory motion which is spontaneously generated as the nuclear model departs from the critical form of unstable equilibrium and which causes a cyclic swelling and shrinking of the equatorial portion, coupled with pauses or even recessions in the elongation of the drop. Several cycles of this quadrupole oscillation are observed in each fission act and seem to accumulate energy from the primary fission mode. A dynamic instability of the elongating form is thus indicated; its possible contribution to the pronounced asymmetry of nuclear fission will be discussed. The asymmetric oscillations deriving from the zero-point excitation of the model and previously reported,* appear likewise to gather some energy as fission proceeds. The fact that a possible charged meson field may be expected to adjust to minimum energy rapidly in comparison with the adjustment of the inertial field suggests that preferred nucleon configurations in the nascent fragment nuclei may be readily formed, contributing to a possible early rupture of the nucleonic bonds at a transient constriction produced by the above mentioned ripples of the elongating form.

* A.P.S., New York meeting (February, 1950).

B2. Ionization Yields of Fission Fragments.* R. B. LEACHMAN, *Iowa State College.*—Ionization chamber measurements for fission fragments are difficult to interpret in terms of kinetic energies because the energy-ionization conversion ratio, w, is not accurately known. In order to determine the relative variation of w with fragment mass, a comparison has been made between fission fragment mass[1] and ionization distributions.[2] It appears that for the most probable mass ratio of U^{235} slow neutron fission the value of w for the light fragment is about three percent less than for the heavy fragment, which is in agreement with an estimate that about 6 Mev of kinetic energy is lost through nuclear collisions not producing ionization. In the course of this determination it is found that the total energy dispersion, which represents a combination of instrumental errors and recoil energy from neutron emission, has a distribution width at half-maximum of roughly $10\frac{1}{2}$ Mev. This width is about one-half as large as the distribution width observed in the total energy for a fixed fission mass ratio.

* Work performed in the Ames Laboratory of the AEC.
[1] Plutonium Project, Rev. Mod. Phys. **18**, 513 (1946).
[2] D. C. Brunton and G. C. Hanna, Phys. Rev. **75**, 990 (1949).

B3. Ionization Yields of Heavy Particles.* J. K. KNIPP, *Iowa State College.*—A heavy particle which is stopped in a substance of about the same atomic number loses energy predominantly in nuclear collisions after its velocity falls below $(Z/20)^{\frac{1}{2}}e^2/\hbar$. Since the recoiling nuclei are of lower velocity and hence themselves lose energy predominantly to nuclei, this is a critical velocity below which ionization yields are relatively small. More generally, particle losses to atomic nuclei predominate below $(Z^{4/3}Z_a{}^{5/3}m/\mu)^{\frac{1}{2}}e^2/\hbar$, where μ/m is the reduced mass of particle and atom in units of the electron mass and Z and Z_a are the atomic numbers of particle and atom, respectively. For $Z<Z_a$ this is also the critical velocity and for $Z>Z_a$ it is very nearly so except for the extreme case in which the recoiling nuclei are on the average of sufficient velocity to be effective in ionization. The energy associated with the critical velocity is largely undetected in the usual ionization measurements.

* Work performed at the Ames Laboratory of the AEC.

B4. Delayed Neutrons From U^{238} and Th^{232} Fission.* K. H. SUN, R. A. CHARPIE, F. A. PECJAK, AND B. JENNINGS, *Westinghouse Research Laboratories,* AND J. F. NECHAJ AND A. J. ALLEN, *University of Pittsburgh.*—The half-lives of the delayed neutrons from U^{238} and Th^{232} fission were found to be 0.4, 1.7, 5.8, 22.6, and 55, and 0.4, 1.4, 4.4, 20, and 56 sec., respectively, by using fast neutrons from 15-Mev cyclotron deuterons on a thick carbon target. These may be compared

with 1.1, 4.5–5.2, 22.6, and 55–55.2 and 0.36–0.43, 1.1–1.8, 4.4–5.5, 22–23, and 55–56 sec. from slow neutron fission of Pu^{239} and U^{235}, respectively, found by various investigators.[1] Evidently the delayed neutron emitters from Pu^{239}, U^{235}, Th^{232}, and U^{238} fission are identical in the life region indicated. The delayed neutron yield after 300 sec. of bombardment was about eight per 100 fissions. A preliminary survey indicated that the 23- and 56-sec. half-lives were also present when LiF or B_4C instead of carbon was used as the cyclotron target for the neutron source.

* Assisted by the joint program of the AEC and ONR.
[1] E.g., Phys. Rev. **72**, 541, 570, 567 (1947); **73**, 111 (1948); **74**, 1330 (1948).

B5. Fission Excitation Functions for Charged Particles. J. JUNGERMAN, *University of California, Berkeley.**—Absolute fission excitation functions have been measured using an ionization chamber to detect the pulse of a recoiling single fragment. In the experiment performed using the 60-in. Crocker cyclotron deuterons and alpha-particles were used with Th^{232}, U^{235}, and U^{238} targets. Thresholds of these reactions were also observed. The maximum alpha-particle energy used was 33.5 Mev and the maximum deuteron energy was 17.5 Mev. Beam current was integrated using both a Faraday cup and an ionization chamber. The 184-in. synchrocyclotron was used to extend the fission excitation functions to alpha-particle energies of 390 Mev and deuteron energies of 193-Mev Bi^{209} and Au^{197} targets were also added. Preliminary results with protons of 340-Mev maximum energy will also be reported.

* Present address: Floyd Newman Laboratory of Nuclear Studies, Cornell University, Ithaca, New York.

B6. The $Ca^{40}-A^{40}$ Mass Difference and the Radioactivity of K^{40}.* T. R. ROBERTS AND ALFRED O. NIER, *University of Minnesota.*—The mass difference, $Ca^{40}-A^{40}$, has been measured as $(3.2\pm0.8)\times10^{-4}$ AMU by comparing the mass doublets $C_3{}^{12}H_4-Ca^{40}$ and $C_3{}^{12}H_4-A^{40}$ in a double-focusing mass spectrometer. This is to be compared with the value $(2.7\pm2.1)\times10^{-4}$ AMU obtained by Sailor[1] from disintegration data. The present results combined with 1.41 ± 0.02 and 1.54 ± 0.1 Mev for the end point of the beta-spectrum and gamma-ray, respectively, as given by Hirzel and Wäffler[2] indicate an excited state of A^{40} 0.17 ± 0.13 Mev below the ground state of K^{40}. This precludes positron emission to the excited state of A^{40}. A determination of the $K^{40}-A^{40}$ mass difference now under way will furnish additional independent data for making comparisons. The Ca^{40} and A^{40} packing fractions as found from the above doublets were -6.11 ± 0.02 and -6.19 ± 0.02, respectively.

* Supported by the joint program of the ONR and AEC.
[1] V. L. Sailor, Phys. Rev. **75**, 1836 (1949).
[2] O. Hirzel and H. Wäffler, Phys. Rev. **74**, 1553 (1948).

B7. Integral Relationships between Atomic and Nuclear Quantities. ENOS E. WITMER, *University of Pennsylvania.*—The writer has pointed out before that one-eleventh of the electron mass appears to be a natural unit for nuclear masses. Designating this unit *the prout*, the accurate data on light nuclei are in harmony with the idea that *the masses of all nuclei in the ground state, provided it is not subject to β-decay, are an integral number of prouts. Some of the nuclear masses excluded by this statement follow the integral rule.* In prouts the masses of the nuclei up to and including C^{12} contain an unusual number of powers of 2 as factors. Thus the neutron mass is $(2^8\times79)$ prouts. This may be significant. In a recent abstract the writer pointed out that the fundamental atomic constants may be calculated very accuretely from $R\infty$, N, and c and the assumptions that (hc/e^2) is 861 and (M_p/m) is 1836 exactly. It is interesting to note that the value of e obtained in this way, namely $(4.80290\pm0.00020)\times10^{-10}$ e.s.u., is in excellent agreement with the value calculated from a recent value of the Faraday,[1] namely $(4.80277\pm0.00080)\times10^{-10}$ e.s.u.

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

B8. Evidence from Nuclear Masses on Proposed Closed Shells at 20 Nucleons.* C. H. TOWNES AND W. LOW, *Columbia University.*—Microwave measurement of the mass differences $S^{34}-S^{36}$, $Cl^{35}-Cl^{37}$, and $Cl^{35}-Cl^{36}$ together with a series of nuclear reactions permit the evaluation of masses between $A=31$ and $A=43$ and with neutron numbers $N=17$ to $N=22$. Nuclear shell structure suggests that nuclei with 20 neutrons or 20 protons should be particularly stable and that after subtracting the odd-even mass variation a plot of the isotopic masses *versus* number of neutrons should show a change in slope at 20 neutrons. However, such plots for $Z=16$, 17, 18, and 19 show no difference in binding energy greater than $\frac{1}{2}$ Mev between the 20th and 21st neutron due to shell structure. On the other hand, for $Z=20$ (Ca^{40}) this difference appears to be 3.5 Mev. Similarly there is no evidence of a closing of proton shells at 20 protons for various N's except in the case $N=20$ (Ca^{40}). Hence the shell which is expected to be closed at 20 particles does not produce a major change in binding energy, and is not simply connected with the well-known stability of Ca^{40}. The Ca^{40} binding appears rather to be peculiar to this nucleus instead of being due to the closing of shells at 20 nucleons.

* Work supported jointly by the Signal Corps and ONR.

B9. The Packing Fraction Curve in the Neighborhood of the Magic Number $n=50$.* HENRY E. DUCKWORTH, KARL S. WOODCOCK,† AND RICHARD S. PRESTON, *Wesleyan University.*—A large Dempster-type double-focusing mass spectrograph has been used to photograph the following doublets $C_2H_2-Pd^{104}$, $C_2H_3-Pd^{108}$, $C_2H_2-Cr^{52}$, $C_2H_3-Fe^{54}$, $Cr^{52}-Pd^{104}$, $Fe^{54}-Pd^{108}$, CH_3-Si^{30}, $Si^{30}-Zr^{90}$, C_2-Mo^{96}, and C_2H-Mo^{100}. Precision masses, obtained from the measurement of these photographs, will be reported for Zr^{90} (50 neutrons), Mo^{96} (54 neutrons), Mo^{100} (58 neutrons), Pd^{104} (58 neutrons), and Pd^{108} (62 neutrons). Preliminary measurements from these photographs, made at the time of the writing of this abstract, indicate a sudden break in the packing fraction curve at, or in the neighborhood of, Zr^{90}. Photographs of typical doublets will be shown.

* This work was supported by the AEC.
† On leave from Bates College.

B10. A Technique for Measuring Meson Production Cross Sections in the Forward Direction.* H. A. WILCOX, W. F. CARTWRIGHT, C. RICHMAN, AND M. N. WHITEHEAD, *University of California, Berkeley.*—In a previous communication[1] a method was described for measuring the positive and negative π-meson production cross sections of various nuclei when bombarded by 345-Mev protons in the external beam of the synchro-cyclotron. The method was successfully applied to mesons produced at 90° to the beam in carbon[1] and in lead.[2] For observations in the extreme forward direction, however, the heavy proton background has made it necessary to extend this technique by introducing a magnetic field in the region about the target. Negative mesons are deflected in this field to one side and positive mesons and protons are deflected to the other. Curved channels in large shielding blocks are arranged so as to select roughly equimomenta particles which then enter and stop in absorber blocks containing embedded nuclear emulsions. A complete spatial separation is obtained between the protons and the positive mesons since the mesons penetrate much more deeply into these blocks than do the heavier protons having the same momenta. Preliminary results on the

forward production from carbon and hydrogen will be presented.

* This work was supported by the AEC.
[1] C. Richman and H. A. Wilcox, Phys. Rev. (to be published).
[2] M. Weissbluth, Phys. Rev. (to be published).

B11. Energy Loss of Million-Volt Electrons. ROBERT D. BIRKHOFF,* EARL E. HAYS,† AND S. A. GOUDSMIT,† *Northwestern University.*—A line source of a beta-active substance was placed parallel to the lines of force in a vertical homogeneous magnetic field. The electrons were restricted by baffles to move along helical paths of 10.75 to 11.25 cm radius. Thin foils were placed in their path at 180° from the source. The displacement of the linear focus at 360° was measured photographically and with counters. A counter was placed 12.8 cm below the source along the lines of force. It could be moved radially and the position of maximum intensity was observed. These measurements give the most probable, rather than the usual, average energy loss. By varying the field, the kinetic energy of the selected electrons was varied from 0.25 to 1.5 Mev. The following foils were used: Be (16.0 mg/cm²), Al (4.7, 14.0, and 37.0 mg/cm²), Ag (5.35 and 10.5 mg/cm²), Ta (10.0 mg/cm²). Comparison with the theory of Landau for the most probable energy loss shows reasonable agreement. Facilities of Argonne National Laboratory were kindly put at our disposal for this work.

* Now at the University of Tennessee, Knoxville, Tennessee.
† Now at Brookhaven National Laboratory, Upton, Long Island, New York.

B12. Search for Gamma-Rays from Nuclei Exposed to Synchrotron Radiation.* J. C. KECK, M. STEARNS, AND R. R. WILSON, *Cornell University.*—An investigation is being made of the production of energetic gamma-rays by nuclei in the photon beam of the synchrotron. Two scintillation counters so placed that the beam passes between them are used as the energy sensitive detectors. The counters consist of activated NaI crystals, each 4 cm in diameter and 5 cm long, facing photo-multiplier tubes. The crystals can be surrounded by 2 r.l. of lead to increase the efficiency at high energies. By adjusting a discriminator bias, the energy threshold can be changed from about 10 to 100 Mev. Calibration has been made against the γ-rays of Co, Th C″, and the Li(p,γ) reaction. A pulsed light source is used to extend the calibration to higher energies. Good collimation of the primary γ-ray beam results in very low backgrounds at large angles. Individual counts, coincidences, and delayed coincidences (assumed casuals) are recorded. Preliminary measurements at 220 Mev indicate that the cross section for emission of energetic gamma-rays in coincidences from Be is $<10^{-29}$ cm² per nucleus per photon per logarithmic energy interval. More sensitive measurements extending to higher energies are in progress. Single high energy particles are observed but positive identification has not been made.

* Supported by ONR.

B13. Coincidence Efficiency of Gamma-Rays. J. M. BARNOTHY AND M. FORRO, *Barat College.*—Several years ago the authors[1] found at great depth a scarcely ionizing radiation of local origin. Later measurements[2] were also not able to settle definitely the question whether this local radiation is a decay product of the penetrating cosmic radiation, or the gamma-radiation of the surrounding materials. To clear this point, investigations were carried out to determine the dependency of the coincidence efficiency of gamma-rays from the energy of the gamma-rays, from the aperture of the coincidence equipment, from the material and wall thickness of the G-M counters, and from the circumstance that the gamma-ray source emits one or two gamma-rays simultaneously. The experiments were sponsored by a grant of Research Corporation.

[1] J. Barnothy and M. Forro, Phys. Rev. **55**, 870 (1939).
[2] J. Barnothy and M. Forro, Phys. Rev. **74**, 1300 (1948) and Miesowicz Jurkiewicz, and Massalski, Phys. Rev. **77**, 380 (1950).

THURSDAY MORNING AT 10:00

National Academy

(E. P. WIGNER presiding)

Theoretical Physics

C1. Effect of a Finite Groundplane on Antenna Radiation.* ALFRED LEITNER, *New York University* AND R. D. SPENCE, *Michigan State College.*—The field of a quarter-wave dipole antenna over a circular groundplane is calculated exactly. The Green's function is represented in terms of the oblate spheroidal wave functions, and satisfies approximate boundary conditions on the conducting circular disk of zero thickness and radius a. Thus both the current on the groundplane and the radiation at large distances are found. (Alternatively, one may calculate the current on the groundplane by applying the reciprocity theorem, after Papas and King.[1]) As a is increased, the radiation resistance and the surface current oscillate about the values which characterize a quarter-wave antenna above an infinite groundplane. The radiation pattern, however, is entirely different. The results are in good quantitative agreement with those of recent experiments by Meier and Summers.[2]

* Supported in part by Geophysical Research Directorate, Air Force Cambridge Research Laboratories, A. M. C.
[1] Papas and King, J. App. Phys. **19**, 808 (1948).
[2] Meier and Summers, Proc. I. R. E. **37**, 609 (1949).

C2. Finite Wiener-Hopf Equations. RICHARD LATTER, *Rand Corporation.*—The Wiener-Hopf technique has been applied to obtain solutions for a class of integral equations of the form:

$$\text{(i)} \quad f(x)=\lambda\int_0^a dy K(x-y)f(y)$$

$$\text{(ii)} \quad f(x)=g(x)+\lambda\int_0^a dy K(x-y)f(y).$$

Solutions have been obtained for those cases in which the Generalized Fourier transform* of the kernel $K(x)$ has no essential singularities or branch points. A general class of kernels consistent with these conditions is that in which $K(x)$ is a sum of polynomials times exponentials. The more important problems wherein the transform of the kernel has essential singularities or branch points (as for diffraction by a finite slit or diffusion through a finite slab) have not yet been solved.

* Titchmarsh, Fourier Integrals.

C3. Quantum Mechanical Resonance between Identical Big Molecules. HERBERT JEHLE, *University of Nebraska.*—A macromolecule which has a rigid structure will perform thermally excited vibrations of the type of an orchestra. This term is meant to imply that the molecule has several commensurable modes which, due to anharmonic terms in the vibrators' potential energy, are coupled. In correspondence terms this coupling causes statistically preferred phase relations in between the phases of the modes. A pair of molecules will interact with each other through their vibrating electric dipole moments. If the molecules are identical, both molecules prefer to perform the same phase-related vibration and will then interact very strongly. They will tend to orient themselves so that they are parallel in the z direction and antiparallel in the x and y directions. Some simplified models of this situation have been calculated by straightforward quantum mechanics. The previous qualitative correspondence arguments are justified by the quantum mechanical calculations. This attractive interaction is seen to be a quantum effect proportional to R^{-7} whose essential features are given by first-order perturbation theory; the second-order theory brings out the relation to Londons dispersion forces. Self-duplication of genes and viruses depends on this attraction which is very specific, depending on identical structures.

C4. On the Theory of Van der Waals Forces. FRANKLIN C. BROOKS, *Yale University.*—The usual method of calculating Van der Waals forces employs the classical electrostatic interaction energy between the molecules as a perturbation on the unperturbed state of the compound system. The shift in energy caused by this interaction is evaluated using the Schrödinger perturbation theory or the variation method. For this purpose the interaction is frequently expanded in inverse powers of the internuclear distance, R. This expansion does not converge everywhere in the configuration space of the compound system, and its use causes the Van der Waals energies, expressed as a series in inverse powers of R, to be divergent for all values of R. These series are, in fact, asymptotic in the sense of Poincaré to the true interaction. As such they are satisfactory for determining the true interaction at large internuclear distances providing they are cut off after an appropriate number of terms. For small R, however, they greatly overestimate the true polarization force. At intermediate values of R, for instance the position of the Van der Waals minimum in helium, a rough calculation of the maximum possible error caused by the use of the divergent expansion gives an upper bound for the helium atom interaction energy curve which is in good (although perhaps accidental) agreement with recent low temperature determinations.

C5. On the Notion of Pressure in a Canonical Ensemble. R. J. RIDDELL, JR., *University of Michigan.*—A discussion will be given with regard to a recent controversy between J. de Boer[1] and H. S. Green[2] concerning the notion of pressure in a canonical ensemble. The question is whether the pressure as derived from the partition function (thermodynamic pressure) is always identical with the "kinetic" pressure as derived from the virial theorem. De Boer's answer is in the affirmative, and we will confirm his view. The origin of the discrepancy which Green finds between the kinetic and the thermodynamic pressure lies, in our opinion, in the treatment of the boundary conditions due to the potential of the wall of the vessel in which the system is enclosed. Green (and also de Boer) represents the vessel by a sudden infinite potential jump, and it is well known that with such potentials the formulas of the transformation theory have to be used with caution.

[1] J. de Boer, Physica **XV**, 843 (1949).
[2] H. S. Green, Physica **XV**, 882 (1949).

C6. Irreversibility and the Statistical Mechanical Derivation of the Equations of Hydrodynamics. JOHN M. RICHARDSON, *Bureau of Mines.*—A general classical theory of irreversible processes recently developed by the author is applied here to the derivation of the hydrodynamical equations of a one-component system involving pair interactions between spherical molecules. The first step is to define functions of coordinates and momenta which, when averaged, will be densities of mass, momentum, and momentum-momentum, respectively. The general theory requires that mass density in pair-space be considered in addition to that in ordinary space in order that the Hamiltonian can be represented as a linear superposition of the observables. Exact expressions for the time derivatives of the above observables are obtained. Certain approximations are applied to reduce these to the familiar form of the hydrodynamical equations. However, the results thus obtained are completely non-statistical and, even after ensemble averaging, leave no room for dissipation and irreversibility. According to the general theory, irreversibility is appropriately treated in a manner automatically satisfying the second law if the time derivatives of the observables are replaced by finite differences over a certain interval τ (of sufficient duration to establish approximate equilibrium with respect to degree of freedom not defined by the observables). Then the resulting expressions are ensemble averaged with a "coarse-grained" phase density equal to an exponential function of a linear combination of observables.

C7. Removal of Degeneracy in Any Order. MELVIN LAX, *Syracuse University.*—The vanishing (or small) energy denominators in a conventional perturbation expansion associated with exactly (or approximately) degenerate states may be avoided by treating perturbation-wise only the part of the interaction matrix V not involving these states in *either* index. If P is a projection operator selecting the subspace of hilbert space associated with the degenerate states and $Q=1-P$ the Schrödinger equation $(E-H)\Psi=(P+Q)V(P+Q)\Psi$ may be split into a pair: $(E-H-QVQ)(Q\Psi)=QV(P\Psi)$ and $(E-H-PVP)(P\Psi)=PV(Q\Psi)$. The "external" wave function $(Q\Psi)$ may be eliminated in favor of $(P\Psi)$ the part of Ψ appropriate to the degeneracy box: $(Q\Psi)=(QS)(P\Psi)$ where $(QS)=[1-(E-H)^{-1}QVQ]^{-1}(E-H)^{-1}QV$. The resulting equation for the exact "starting approximation" is $(E-H-PKP)(P\Psi)=0$ where $K=V+VQS$. Thus the energy levels, and the correct linear combinations $(P\Psi)$ of (almost) degenerate states are obtained by diagonalizing $H+PKP$, i.e., solving a finite set of linear equations. K and QS are equivalent to the usual perturbation expansions for energy and wave function with all degenerate indices removed from the summations. This procedure has the advantage (1) that any group of states, possibly non-degenerate, may be treated in semi-exact fashion. (2) Only one secular change of base need be made regardless of the order of accuracy desired.

C8. The Uncertainty Principle for an Arbitrary Number of Variables. RONALD L. REED AND M. DRESDEN, *University of Kansas.*—For two variables the uncertainty principle is an immediate formal consequence of Schwartz' inequality. A similar derivation for an arbitrary number of variables requires a generalization of this inequality. To obtain this one utilizes the known expression of the Schwartz inequality for two vectors in a space, which itself is the direct sum of a countable number of identical unitary spaces. The resulting inequality is

$$|\Sigma_i (f_i, g_i)|^2 \leqslant \Sigma_{ij} \|f_i\|^2 \|g_j\|^2.$$

Here f_i and g_i are vectors in a unitary space. If now R_i and S_i represent a set of observables as well as their corresponding Hermitean operators, it is possible to deduce from this inequality, the uncertainty principle for an arbitrary number of variables

$$\Sigma_{ij} (\Delta R_i)^2(\Delta S_j)^2 \geqslant [\Sigma_i \tfrac{1}{2}\langle [R_i, S_i]_+\rangle_{Av} - \bar{R}_i\bar{S}_i]^2 - \tfrac{1}{4}[\Sigma_i \langle [R_i, S_i]_-\rangle_{Av}]^2.$$

It is interesting to observe that in general the lower limit will depend explicitly on the state of the system. This will be exemplified by applying this inequality to a system consisting of an infinite set of oscillators.

C9. On the Role of the Subsidiary Condition in Quantum Electrodynamics. F. COESTER AND J. M. JAUCH, *The State University of Iowa.*—The S-matrix in quantum electrodynamics may be calculated alternatively from the Hamiltonian density $-j^{\mu}(x)A_{\mu}(x)$ and a Hamiltonian in which the Coulomb interaction of the charges and the interaction of the currents with the transverse field are separated. Both procedures lead to identical S-matrices if proper care is taken in defining the initial state, in particular the initial vacuum state. It is essential that the initial state is taken at the time $\tau=-\infty$. Only then is the definition of the vacuum state the same in both representations.

C10. Conservation Laws in Einstein's Theory of Gravitation with Electromagnetic Field.* ROBERT PENFIELD AND HENRY ZATZKIS, *Syracuse University.*—In a fully covariant theory, the energy and momentum contained in a three-dimensional domain can always be converted into an integral over its two-dimensional surface. This representation is particularly important when the domain contains singularities; it is analogous to the surface integral over **D** in Maxwell's theory that measures the amount of charge inside. Freud[1] has given the correct integrands for the purely gravitational case. We have added to Freud's expressions the contributions of the electromagnetic field, so that we are able to determine the energy and the linear momentum associated with a system of charged mass points. These expressions obey conservation laws in every possible coordinate system and gauge frame in that their rates of change are determined by flux expressions through the bounding surface. But they are not covariant quantities: Under certain conditions all components may vanish in one coordinate system, but not in another. As an illustration, we have computed the total energy of a Schwarzchild singularity with electric charge at rest in two different coordinate systems; the two results differ significantly.

* Supported by ONR.

[1] Ph. v. Freud, Annals of Mathematics **40**, 417 (1939).

C11. Equations of Motion in the Covariant Canonical Formulism.* PETER G. BERGMANN, ROBERT PENFIELD, RALPH SCHILLER, AND HENRY ZATZKIS, *Syracuse University.*—Using the expression for the Hamiltonian of the General Theory of Relativity presented at the New York meeting, we have derived the expression for the rate of change of linear momentum for a field singularity corresponding to an electrically charged mass point, i.e., the "force" acting on it. The mass and the linear momentum are defined as the surface integrals described in the preceding abstract. At a time t_0 the field variables and the momentum densities must be chosen so that all the constraints between them are satisfied. Then the canonical equations determine uniquely the values of all time derivatives of finite order of any dynamical variable, including integrals. The calculations are lengthy, but lead to the desired result, showing that the force is the combined electrostatic and gravitational force. This derivation leads to rigorous expressions insofar as nowhere do we introduce power series expansions in c^{-2}. Otherwise, our method is equivalent to that of Einstein, Infeld, and Hoffman.

* Supported by ONR.

C12. Gravitational Radiation and Motion. A. E. SCHEIDEGGER AND L. INFELD, *University of Toronto.*—It is known[1] that one can set up an approximation procedure for obtaining the equations of motion from the field equations in relativity theory. In such a scheme there is an ambiguity which can be restricted by choosing a set of co-ordinate conditions. Changing those co-ordinate conditions alters the equations of motion. We show that there exist co-ordinate transformations which change the usual equations of motion of (1) into equations whose analogues in linear theories describe radiation damping. Conversely, all relativistic radiation damping effects hitherto calculated are shown to be due to a particular choice of the co-ordinate system. They have no physical meaning if the approximation procedure is adopted. Furthermore, we show that it is always possible to find such a co-ordinate system that the form of the equations of motion is Newtonian. Then, the relativistic effects are described by the metric field alone. This yields a new version of the approximation method where co-ordinate transformations play the same role as dipoles in (1) toward the vanishing of certain surface integrals and the fulfilment of the integrability conditions.

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

C13. Stability of Systems and General Principles. ROBERT E. BASS, *University of Toledo.*—The earth's velocity and position at any time are so that from these conditions and from laws connecting cause and effect ("causal laws") continued existence of the orbit follows; Newton remarked that the stars have such mutual distances that they will not collide;—Einstein[1] rejected the hypothesis that the stellar universe is a finite island in infinite space, since such an island would irretrievably lose energy. Such highly differentiated systems as the solar system, star systems, and the stellar universe are "stable" which means they are fit for continued existence. This property is rooted in simultaneously existing conditions which have, in some cases, been proved to follow from certain earlier simultaneous conditions. Fitness for continued existence involves a relation between simultaneous facts. Causal laws alone cannot establish such a relation. Such fitness contains, therefore, an element irreducible to causal laws and is, in this sense, a basic property. In the author's view this result applies to the whole of nature, also to fitness for continued existence of single organisms, species, and life as a whole.

[1] A. Einstein, *Relativity* (New York, 1921), p. 169.

C14. Self-Energy of Moving Free Electron. F. J. BELINFANTE, *Purdue University.*—Assuming that integration over angles gives $\int d^3\mathbf{k}(\boldsymbol{\alpha}\cdot\mathbf{k})/k^3=0$, French and Weisskopf proved that the free-electron self-energy S calculated separating longitudinal electromagnetic fields equals the self-energy C obtained using a quantized covariant potential four-vector. Umezawa and Kawabe[1] recently defined a covariant cut-off enabling them to obtain by ordinary perturbation theory Schwinger's expression for the **C**-self-energy of a free moving electron $C=(3\ln Z-\frac{1}{2})K\beta$ with $2\pi K=(e^2/\hbar c)mc^2$ and $mc^2Z=$cut-off in electron rest-system for $(c\rho_i+E_i)$ of electronic intermediate state. Using the same method we find for the **S**-self-energy $S=C+T-(K/3mc)(\boldsymbol{\alpha}\cdot\mathbf{p})$ with $T=[\rho^2\beta-mc(\boldsymbol{\alpha}\cdot\mathbf{p})]\cdot f(\rho)=0$. This apparent discrepancy with French and Weisskopf's result is due to $S-C=(-e^2/4\pi^2)\int d^3\mathbf{k}(\boldsymbol{\alpha}\cdot\mathbf{k})/k=(-e^2/6\pi\hbar)(\boldsymbol{\alpha}\cdot\mathbf{p})\neq 0$ by this cut-off method. After formal "mass-renormalization" this leaves in the **S**-theory a small finite negative "self-energy of motion" of a free moving electron $S-C\approx(-1/1291)(mv^2/2)(1-v^2/c^2)^{-\frac{1}{2}}$.

[1] H. Umezawa and R. Kawabe, Prog. Theor. Phys. **4**, 420, 461 (1949).

THURSDAY MORNING AT 10:00

National Bureau of Standards

East Building Lecture Room

(F. SEITZ presiding)

Miscellany in Solid-State Physics

D1. The Heat Capacity of Liquid Mercury between 0° and 450°C. T. B. DOUGLAS, ANNE F. BALL, AND D. C. GINNINGS, *National Bureau of Standards* (Introduced by F. G. Brickwedde).—Using an improved ice calorimeter and furnace, the enthalpy referred to 0°C of a sample of highly purified mercury has been measured by a drop method at nine temperatures between 0° and 450°C (up to a saturation pressure of approximately five atmospheres). The precision obtained is equivalent to an average probable error of the mean relative enthalpy for a given temperature in this range of 0.02 percent. A check on the accuracy of the method was afforded by measuring the enthalpy of water between 0° and 250°, with a variation of 0.02 percent from the precise value obtained earlier in this laboratory by use of an adiabatic calorimeter. Values of entropy and specific heat were derived from the data. The probable uncertainty in the values of heat capacity, estimated to be less than 0.3 percent, is much smaller at the higher temperatures than the wide discrepancies among the results of the earlier workers who measured mercury. As has been found in this laboratory analogously for liquid sodium and potassium, mercury shows a shallow but definite minimum in its specific heat (C_p), as a function of temperature, somewhat below its normal boiling point.

D2. The Heat Capacity of Sodium between 0° and 900°C. D. C. GINNINGS, T. B. DOUGLAS, AND A. F. BALL, *National Bureau of Standards* (Introduced by F. G. Brickwedde).—In the measurements of heat capacities at high temperatures by the drop method, the furnace and ice calorimeter have been improved to give more accurate results with easier manipulation. The enthalpy of sodium has been measured from 0° to 900°C, and values of heat capacity and entropy have been derived. Liquid sodium was found to have a minimum heat capacity at about 600°C, in agreement with current theories that the metal does not acquire complete randomness on melting.

D3. Effect of Heat Treatment on the Electrical Properties of Platinum. ROBERT J. CORRUCCINI, *National Bureau of Standards* (Introduced by R. E. Wilson).—The average temperature coefficient of resistance over the interval 0° to 100°C, α, and the thermal e.m.f. are often used as criteria of the purity or freedom from strain of platinum. Ordinarily, both increase of purity and relief of strain (by annealing) result in increase of coefficient of resistance and decrease of thermal e.m.f. towards limiting values of, respectively, $\alpha=0.003927$ and $E_{0°}{}^{1200°}=-10$ microvolts (referred to Pt27, the platinum thermoelectric standard of the NBS). The relation between α and E for annealed samples of platinum of various degrees of purity has been found to be

$$\alpha=0.003922-0.5\times10^{-6}E_{0°}{}^{1200°}\ (vs.\ \text{Pt27})$$

provided the impurity, gold, is absent. In the present investigation it was found that quenching pure platinum wires from a temperature of 1450°C in various gaseous media caused a decrease in α and an increase in E relative to the annealed condition, the changes being greater, the more rapid the cooling of the wires. The effect, which is analogous to a strain, was removed by annealing at 500°C or above, followed by slow cooling. The relation between α and E for samples of pure platinum quenched at various rates was the same as the relation given above for variation due to impurity.

D4. On the Theory of Beta-Brass Structure. LOUIS GOLD, *University of Colorado.*—It is generally believed that beta-brass has the CsCl-type structure.[1] Studies of the order-disorder process in the alloy Cu Zn have been handicapped by the well-known limitation imposed by the similar x-ray scattering powers of the two elements[2] so that it has not been possible to estimate the degree of long range order at specified temperatures. The present paper is intended to show that on the basis of extant data it is reasonable to formulate a structure whose space group is $O_h{}^5$-$Fm3m$. There are two major consequences of the hypothesized structure: first, the superlattice lines ordinarily related to the ordered position of the copper and zinc atoms in the CsCl structure are associated with superlattice lines in the new structure which vanish for either complete order or disorder, and second, a new set of lines arise which have no analog in the conventional beta-brass structure. These lines having $\Sigma H^2=3$, 11, 19, 27—etc., do not conform to the transformation $4\Sigma h^2=\Sigma H^2$ between the two possible structures. Further experimental investigations are needed to resolve the situation.

[1] F. W. Jones and C. Sykes, Proc. Roy. Soc. **161**, 440-446 (1937).
[2] B. E. Warren and D. Chipman, Phys. Rev. **75**, 1629 (1949).

D5. A Dislocation Model of a Kink Band.* J. S. KOEHLER AND E. SALKOVITZ, *Carnegie Institute of Technology.*—Single crystals of hexagonal metals with a c/a ratio exceeding 1.732 can be deformed in compression by kinking providing the basal plane is nearly parallel to the specimen axis. In kinking a certain portion of the length of the specimen rotates about an axis in the basal plane and perpendicular to the slip direction which lies nearly along the specimen axis.[1] Ballistic pendulum measurements on pure zinc cylinders of dimensions 3 cm by 0.6 cm give the length of the kink to be from 0.1 cm to 0.6 cm, the angle of rotation to be from 6° to 14°, and the energy absorbed during kinking to be from 1 to 10×10^5 ergs. The rotated portion of the sample can be made to fit onto the undeformed ends by supposing that the interface contains a large number of edge type dislocations.[1] A theoretical calculation of the interface energy shows that the parallel line dislocations are not uniformly spaced on the interface. Instead they occur in clusters separated by 2 microns; each cluster contains about 1500 dislocations.

* This research was supported in part by ONR Contract.
[1] J. B. Hess and C. S. Barrett, Metals **1**, 599 (1949).

D6. Techniques for Measuring Sound Velocities and Elastic Constants. HENRY L. LAQUER AND WILLIAM E. MCGEE, *Los Alamos Scientific Laboratory.*—Resonance and pulse techniques for the measurement of the velocity of longitudinal and transverse sound waves in solid materials are described. The effects of various factors on the accuracy of the results are evaluated. With specimens of relatively low internal friction, such as most metals, the resonance technique offers precisions of 1 part in 10,000 or better, and is hence most suitable for the determination of the temperature coefficients.

The disadvantages of the resonance technique are that the cylindrical specimens have to be machined accurately, that the surface condition may affect the observed resonance frequencies, and that the methods of producing and observing resonance are somewhat involved. If Radar timing techniques can be taken for granted, the pulse technique is simple, fast and direct. The specimens need to have only two plane and parallel surfaces; however, the maximum pulse frequency is limited in polycrystalline materials and this in turn limits the precision to about 1 part in 2000. This is unfortunate since it is the only technique presently available for use with most plastics and for work on pressure coefficients using liquid pressure systems.

D7. The Structure of Lead Sulfide Films. J. DOUGHTY, K. LARK-HOROVITZ, L. M. ROTH, AND B. SHAPIRO, *Purdue University.*—Films of lead-sulfide, lead-selenide, and lead-telluride obtained by evaporation of the compound onto glass, mica or quartz, and lead-sulfide deposited on the same surfaces from solutions were investigated with x-rays, electron diffraction, and electron-microscope. X-ray diffraction patterns of the freshly deposited lead-sulfide, as well as lead-sulfide films heat treated in air, correspond primarily to PbS, whereas the electron diffraction pattern of the heat treated material corresponds primarily to Lanarkite ($PbO \cdot PbSO_4$). The orientation of the crystallites and their size varies with the type of substrate, the temperature of deposition, and heat treatment of the deposit. Formvar replicas can be made without impairing the light sensitivity of the treated films. Crystal size determined with the electron-microscope varies from $0.1\mu - 1\mu$, the larger crystallites showing well-developed edges. High resistance films show large isolated crystals with a smooth substrate in between. Films of lead-sulfide deposited from solution on Formvar show, also with x-rays additional lines besides PbS (probably $PbO \cdot PbSO_4$).

D8. Temperature Variation of Properties of Photo-Sensitive Lead Sulfide Films.* RAYMOND H. MCFEE, *Photoswitch Incorporated.*—Measurements have been made of dark current, photo-current and noise as functions of temperature between 90°K and 300°K of several typical sensitive lead sulfide cells. Response to 200°C black body radiation both unmodulated and modulated at 90 c.p.s. was measured by means of a special cooling system and high impedance input preamplifier. Dark currents show decrease of four orders of magnitude at 90°K relative to values at 300°K. Photo-currents are roughly constant at higher temperatures and become proportional to dark currents at low temperatures. Sensitivity, defined as the ratio of photo-current to dark current increases with decreasing temperature in some cases by a factor of a thousand over this temperature range. Response to 90 c.p.s. modulated radiation falls off below 180°K due to increase in time constant. Maximum signal-to-noise for this frequency occurs at around 180°K.

* Work performed under contract with the Air Materiel Command.

D9. Hydrogen Bond Energy from A.C. Conduction Data on Ice. E. J. MURPHY, *Bell Telephone Laboratories.*—The a.c. conductivity of ice approaches a limit value as the frequency increases. The limit value may be described as a polarization conductivity or local conductivity of the material because it characterizes the process of forming the polarization and depends upon local mobility rather than upon migration. This local conductivity is an exponential function of the reciprocal of the absolute temperature from which an activation energy can be calculated. Its value for ice is 11.5 kcal./mole. This is in agreement with the heat of sublimation of ice, 11.5 kcal./mole, as calculated by Bernal and Fowler and with the experimental value 11.8. Taking the process of activation as requiring the breaking of two hydrogen bonds, we obtain for the energy per bond 5.75 kcal./mole (or 0.5 electron-volt). This is a determination of the hydrogen bond energy (with an accuracy estimated to be at best ± 0.1 kcal.) from radiofrequency measurements of dielectric properties. It agrees with the value 5.8 ± 0.2 kcal./mole derived from the heat of sublimation of ice by Fox and Martin.

D10. A Phase Transition due to Dipole Interaction in a Simple Cubic Crystal.* JOHN S. THOMSEN AND T. H. BERLIN, *The Johns Hopkins University.*—A simple cubic crystal model with classical dipoles at each lattice point is investigated. The interaction matrix is set up and diagonalized, and an approximate partition function is evaluated by the technique of "sphericalization." This shows a phase transition at a finite temperature. This transition must represent a change from the non-magnetic state to an antiferromagnetic state. (It is noted that one- and two-dimensional models do not exhibit any such transition.) It is hoped that calculations can be made for the internal field in this model.

* Supported by the ONR.

D11. The Effect of Pressure on the Low Frequency Dielectric Constant of Ionic Crystals. SUMNER MAYBURG, *University of Chicago.*—The effect of hydrostatic pressure on the dielectric constant ϵ of MgO, LiF, NaCl, KCl, and KBr at 1000 c.p.s. and room temperature has been investigated to 8000 bars. The dielectric constants were determined from capacity measurement on single crystal slabs. The dielectric constant of these materials decreases linearly with pressure with slopes $\partial \ln\epsilon/\partial p$ of -0.32, -0.45, -0.98, -1.03, and -1.17×10^{-5} bar^{-1} respectively. The observed decrease of the dielectric constant can be qualitatively explained as being caused by the increase, at high pressure, in the resorting forces in the lattice which resist the action of an electric field in its attempt to displace the lattice of positive ions with respect to the lattice of negative ions. Consequently, the lattice polarizability decreases and, in fact, changes enough to outweigh the effect of density changes which tend to increase the dielectric constant. The change of lattice polarizability with pressure can be calculated and it is not found sufficient to explain the observed decrease in dielectric constant. The data can be explained if the inner field decreases with increasing pressure. This concept is consistent with the picture of Mott and Littleton.[1]

[1] N. F. Mott and R. W. Gurney, *Electronic Processes in Ionic Crystals* (Oxford University Press, New York, 1940), Chapter 1.

D12. Vector Functions for Uniform Spheres and Spherical Shells.* DOROTHY WRINCH, *Smith College.*—Let $g(r)$ represent a uniform sphere of radius a and density m from which a smaller concentric sphere of radius b and density n has been deleted and $T(R)$ the Fourier transform. The corresponding vector function $g_v(r)$ is then[1] the Fourier transform of $T^2(R)$ and it follows that

$$12g_v(r)/\pi = m^2(2a-r)^2(r+4a) + n^2(2b-r)^2(r+4b) - 2mn\{16b^3, (a+b-r)^2[r+2(a+b)-3(a-b)^2/r]\},$$

the various functions being taken from $r-0$ to $2a$, $r-0$ to $2b$, $r-0$ to $a-b$, and $r-a-b$ to $a-b$. It has already been shown[2] that the vector function for a crystal may be obtained from the vector function of the crystal reduced to any level, by suitably adjusting its level. Hence the result given for $g_v(r)$ yields the vector map of a crystal comprising a uniform sphere or shell of any densities repeated with any displacements in any constant medium. The bearing of this result on vector maps of hydrated protein crystals will be discussed.

* This work is supported by the ONR.
[1] D. Wrinch, Nature **157**, 226 (1946).
[2] D. Wrinch, Phil. Mag. **27**, 490 (1939).

D13. The Crystal Structure Problem. H. HAUPTMAN AND J. KARLE, *Naval Research Laboratory.*—A complete set of inequalities in the crystal structure factors based on the positiveness of the electron distribution function has been derived.[1] The relation between these inequalities and the equalities which result from the limiting case of the point atom approximation has been studied from the point of view of a set of algebraic equations. The equalities afford a basis for adjusting the observed magnitudes of the crystal structure factors which are known only approximately from experiment. The complex structure factors are also determined. In addition, the solution of the set of algebraic equations permits an evaluation of the coordinates of the atoms in a unit cell in terms of the observed magnitudes. This contrasts with Avrami's[2] formal solution to the problem which requires an exact knowledge of many more magnitudes than are usually determined.

[1] J. Karle and H. Hauptman, Acta Cryst. **3**, 181 (1950).
[2] M. Avrami, Phys. Rev. **54**, 300 (1938).

THURSDAY MORNING AT 10:15

Department of Commerce Auditorium

(E. P. NEY presiding)

Cosmic Rays. I

E1. Monte Carlo Calculations of Showers in Lead. ROBERT R. WILSON, *Cornell University.*—The Monte Carlo method has been applied to the calculation of showers in lead. The initial electron or photon and all degraded radiation are followed through successive distance intervals (0.2 radiation length). At each interval, the radiation or electron production is determined by spinning a wheel of chance. A graph is made for each shower showing the energy-distance history of the initial and secondary particles. From a few hundred such graphs, prepared for each kind of shower, pertinent averages can be taken. Calculations have been completed for 50-, 100-, 200-, and 300-Mev electron- and photon-initiated showers. The results, which differ significantly from those of Arley and from those given by standard shower theory, will be presented. The range and straggling of individual electrons in lead from 10 to 1000 Mev have also been calculated both analytically and by the above method. The mean range in radiation lengths is $\ln 2\ \ln(\beta+E/\beta \ln 2)$ when E and β are the energy and critical energy in Mev. The calculations are being extended to include effects due to multiple scattering. On the basis of the above work, a high efficiency gamma-ray detector with a reasonably sharp high energy threshold has been developed.

E2. On Penetrating Showers and Meson Production.* K. SITTE, *Syracuse University.*—The local production of penetrating showers, both by single penetrating particles and by air shower particles, has been studied at an altitude of 3260 m. From the results, the following conclusions can be drawn: (1) The production in a nuclear collision of a shower containing several penetrating particles becomes probable only at very large primary energies. (2) For smaller primary energies, collisions result predominantly in the ejection of a small number of "knock-on nucleons." (3) The processes in which, directly or indirectly, electrons are released in nuclear collisions are either infrequent at all energies, or confined to very high primary energies.—A discussion of the differences between the geomagnetic latitude effects of the primary radiation and of the sea level hard component, and of the differences between the E-W effects of the sea level hard component between equator and moderate latitudes, shows that these effects are well compatible with the above conclusions.

* Supported in part by AEC contract.

E3. On the New Unstable Cosmic-Ray Particles.* A. J. SERIFF, R. B. LEIGHTON, C. HSIAO, E. W. COWAN, AND C. D. ANDERSON, *California Institute of Technology.*—Thirty-four "forked tracks" similar to two previously reported by Rochester and Butler,[1] have been observed in 11,000 cloud-chamber photographs of cosmic-ray penetrating showers, confirming their conclusion that new unstable neutral and charged particles exist. The neutral particles decay into two charged particles (and possibly into neutral particles also) and the charged particles into a charged particle and presumably at least one neutral particle. The unstable neutral particles have a mean rest life time of $(3\pm2)\times10^{-10}$ sec., and the unstable charged particles a mean life perhaps shorter, but of the same order of magnitude. The number of unstable neutral particles is about three percent of the number of charged particles in a penetrating shower. Of the two charged secondaries of the unstable neutral particles, curvature and ionization show that at least one has a mass between 150 m_e and 350 m_e, and large angle scattering and star production show that at least one has a strong nuclear interaction; the data also indicate that neither of the decay products is an electron.

* Supported in part by the joint program of the ONR and AEC.
[1] G. D. Rochester and C. C. Butler, Nature **160**, 855 (1947).

E4. A Large Cloud Chamber for the Study of Penetrating Showers.* MELVIN B. GOTTLIEB AND ALFRED J. HARTZLER, *University of Chicago.*—A rectangular chamber with a sensitive volume of $24\times16\times7$ in. has been constructed for the study of high energy nuclear events in which penetrating particles and electron cascades occur. The chamber was expanded on two sides. It thus could be illuminated through the rear glass wall resulting in relatively high light efficiency. About 300 g/cm² of gold in the form of 16 plates of 1 cm thickness were placed in the chamber and inclined toward the cameras. The expansion of the chamber was controlled by a fivefold coincidence between counters located inside of and below the chamber. The inside counters were located in a tray near the center of the chamber. The counters below the chamber consisted of two horizontal trays, one above the other, and were shielded by lead blocks. This counter arrangement proved to be highly selective for high energy nuclear events. Other counters at a distance from the chamber were used for the detection of extensive showers. Events occurring in the chamber were photographed by three cameras for stereoscopic observation. Some of the photographs obtained with this apparatus will be discussed in the following paper.

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

E5. Cloud-Chamber Observations of Showers at an Altitude of 11,500 Ft.* ALFRED J. HARTZLER AND MELVIN B. GOTTLIEB, *University of Chicago.*—The cloud chamber and associated apparatus described in the previous paper were operated at Climax, Colorado (altitude 11,500 ft.) for a period of several months in the fall of 1949. Nine thousand stereoscopic pictures were taken. The gold plates used in this

experiment were particularly valuable for the study of several high energy phenomena. The large amount of material in the chamber (about 300 g/cm²) permitted the observation of a great number of cases in which successive production of nuclear events occurred. In the case of showers containing both penetrating particles and electron cores, the short radiation length in gold (0.3 cm) resulted in the rapid absorption of the soft cascade showers, thus making the penetrating component more easily observable. A number of pictures showed the complete development and absorption of very high energy electron showers. Photographs of typical events will be shown.

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

E6. The Production of High Energy Photons in Nuclear Interactions of Cosmic Rays.* B. P. GREGORY AND J. H. TINLOT,† *M.I.T.*—Seventy-eight electronic showers produced in nuclear interactions occurring in the lead and aluminum plates of a cloud chamber were examined in order to determine whether they were electron- or photon-initiated. All these showers penetrated at least one lead plate (1.2 radiation lengths) and showed a multiplicity of more than four electrons. Under the assumption that the shower-initiating particles are produced at a distance from the origin of the nuclear interaction small with respect to the thickness of the plates, it was established that less than 20 percent of the showers were electron-initiated when the nuclear event occurred in an aluminum plate, and less than 30 percent when the nuclear event occurred in lead. In those two cases, the data were also consistent with all showers being photon-initiated. The possibility of interpreting these photons as the decay products of a neutral meson will be discussed.

* Assisted by the joint program of the ONR and AEC.
† Now at Columbia University.

E7. Cross Sections for Nuclear Collisions of Protons and π-Mesons.* J. H. TINLOT AND B. P. GREGORY,† *M.I.T.*—The cloud chamber described in the previous paper was, in one experiment, triggered by a simple counter telescope above. The observed nuclear collisions of ionizing particles (protons) indicated that the relative cross sections for aluminum and lead were compatible with the assumption of "geometric" cross sections. The energy of the majority of protons was estimated as less than 1 Bev. In a second experiment, the chamber was triggered by a counter telescope below, in anticoincidence with a large tray of counters above. Nuclear interactions of widely varying energies and multiplicity were observed. Of interest were the secondary collisions of the locally produced penetrating particles, which were presumably a mixture of protons and π-mesons. Events were tentatively classified as to multiplicity of penetrating particles, this being a crude measure of the energy transmitted in the collision. A preliminary survey indicated the following.

Multiplicity	Traversals (g/cm² Pb)	Nuclear collisions	M.F.P. (g/cm² Pb)
2–3	1150	3	~400
2–4	2500	12	~200
>4	2000	13	~160

The "geometric" mean free path in lead is 160 g/cm².

* Assisted by the joint program of the ONR and AEC.
† Now at Columbia University.

E8. Altitude and Latitude Dependence of Bursts in a Lead-Shielded Ion Chamber.* ALLEN J. MCMAHON AND BRUNO ROSSI,† *Brookhaven National Laboratory.*—The instrument used in this experiment consists of a cylindrical ionization chamber covered by a half cylindrical lead shell 15 cm thick and of six trays of G-M tubes, of which five are placed around the lead shield and one directly under the chamber. Various kinds of coincidences between bursts of the ionization chamber and pulses of the counter trays are recorded. These events are interpreted as due to nuclear interactions of cosmic rays. The instrument was installed aboard a B-29 and flown at the pressure altitudes of 273, 300, and 383 g cm^{-2} at 55°N geomagnetic latitude, and at the pressure altitudes of 300 and 383 g cm^{-2} at 20°N geomagnetic latitude. The experiment provided information on the altitude, latitude, and angular dependence of the radiation responsible for nuclear interactions. If one considers in particular penetrating ionizing particles capable of producing high energy nuclear events after traversing 15 cm of lead, one finds that the altitude dependence corresponds to an absorption thickness of about 124 g cm^{-2} both at 55° and 20° and that the intensity ratio between the two latitudes is about 1.14.

* Research carried out at Brookhaven National Laboratory under the auspices of the AEC.
† At M.I.T.

E9. Energetic Stars at Different Latitudes.* C. B. FISK, J. HORNBOSTEL, E. O. SALANT, AND J. E. SMITH, *Brookhaven National Laboratory.*—Eastman NTB3 emulsions were flown to an atmospheric pressure of 15 g/cm² at 57° and 31°N** geomagnetic latitudes, cut-offs 2.8 and 8 Bev, respectively. About 1000 stars were examined in plates verified as sensitive to minimum ionization tracks. Latitude effect for star production by incident singly charged, relativistic particles is about the same as reported for particle flux by Winckler *et al.* (private communication), implying approximately constant cross section, over relevant energy ranges, for proton disintegrations. No significant differences between the two latitudes are found for distribution in either numbers of heavy prongs or multiplicities of outgoing minimum tracks. Considering only stars of 3 or more heavy prongs, data at each latitude show: (a) about one-fourth of the stars are caused by relativistic protons, (b) two-thirds of the proton-induced stars have outgoing minimum tracks, presumably mostly relativistic mesons, with an average multiplicity of 3, (c) two-thirds of these stars have 6 or more and one-half have 9 or more heavy prongs, (d) one-half of all stars contain only heavy prongs, of which only one-fourth have 6 or more prongs. This distribution, contrasted with (c), suggests only moderately energetic neutrons as a cause. Angular spreads of minimum tracks will be discussed.

* Research carried out at Brookhaven National Laboratory under the auspices of the AEC.
** Flights by ONR.

E10. Further Experiments on Slow μ-Mesons Stopped at Thin Al Foils.* W. Y. CHANG, *Purdue and Princeton Universities.*—The cloud-chamber-counter arrangement for the more recent work on thin Pb foils[1] was used to continue study of meson absorption by thin Al foils. Eight 4/1000-in. and three 32/1000-in. Al foils were symmetrically placed inside the chamber. The total sensitive time was about 1500 hr. More than 60 mesons were stopped at the Al foils. About half of these are decaying mesons, and the other half do not give rise to an observable heavy charged particle or a decay electron and hence are negative mesons. About 12 of these latter events occur at the 4/1000-in. foils. If, from every negative meson captured by an Al nucleus, a proton with a 3-Mev kinetic energy was emitted, then six out of the 12 pictures should have shown proton tracks. Our results therefore support the view for Al too that the μ-meson gives up its negative charge to the Al nucleus and a much larger portion of its rest energy is emitted as a neutral meson or a neutrino. Since the potential barrier of Mg^{27} for a proton is much smaller than the binding energy of a nucleon, a neutron may escape from a Mg^{27} nucleus without much greater probability than a proton. Our results therefore indicate that the negative μ-meson imparts only about 15 Mev or much less to the Al nucleus, taking 3 Mev to change Al^{27} to Mg^{27}.

* Assisted by the joint program of the AEC and ONR.
[1] Phys. Rev. **76**, 170 (1949); Princeton Biennial Reports on Cosmic Rays, July 1, 1947 to July 1, 1949.

THURSDAY AFTERNOON AT 2:00

Department of Commerce Auditorium

(BRUNO ROSSI presiding)

Cosmic Rays. II

F1. Total Primary Cosmic-Ray Energy at the Geomagnetic Equator.* J. A. VAN ALLEN AND S. F. SINGER, *Johns Hopkins University.*—Our experimental measurements above the atmosphere at $\lambda = 0°$ have given the following results: (a) Vertical intensity 0.028 sec.$^{-1}$ cm^{-2} steradian^{-1}. (b) A marked increase in the intensity, averaged over all azimuths, with zenith angle. (c) Azimuthal asymmetry of the proper sign, but of much less magnitude than predicted for a radiation consisting only of positive primaries. (d) Bulk of the charged radiation singly charged, with specific ionization about minimum. Result (b) is inconsistent with geomagnetic theory for either all positive, all negative, or mixed positive and negative primary beams and, therefore, provides clear evidence for the importance of atmospheric albedo, particularly at large zenith angles. Thus, result (c) can be shown in accord with the assumption that the primaries are positive, but that the east-west asymmetry is diluted by the large contribution of albedo. If one takes the measured vertical intensity as consisting only of primary protons, then with the help of geomagnetic theory, the total energy brought in by the primary radiation can be easily computed. The result is 2.2 Bev (horizontal cm^2)$^{-1}$ sec.$^{-1}$ using a differential number spectrum of $dN = KE^{-3}dE$. A flatter spectrum, based on the latitude variation of vertical intensity above the atmosphere, yields an even larger value for the total energy. Such results can be harmonized with Millikan's value of the ionization energy integral of 0.94 Bev-cm^{-2}-sec.$^{-1}$.

* Supported by the Navy Bureau of Ordnance.

F2. The Daytime Azimuthal Effect for Heavy Nuclei.* E. P. NEY, J. LINSLEY, AND P. S. FREIER, *University of Minnesota.*—A device was constructed to maintain orientation of a plate stack during a high altitude balloon flight. A small sphere containing photographic plates was hung from a large cloud-chamber sphere by a suspension which contained a motor-driven rotating joint. The motor rotated the plate sphere relative to the big one so as to cancel the rotation of the big sphere relative to the ground. The motor was controlled by phototubes coupled with light beams to a compass. Photographic recorders in both spheres showed that during 190 minutes at altitude the orientation of the plate sphere was held constant within $\pm 15°$ for 140 minutes and within $\pm 35°$ for 184 minutes while the balloon and large sphere rotated considerably. The flux of heavy nuclei was measured as a function of zenith and azimuth and the results will be reported.

* This work was supported in part by the ONR.

F3. Nighttime Flux of Heavy Nuclei.* P. S. FREIER, E. P. NEY, J. NAUGLE, AND G. ANDERSON, *University of Minnesota.*—The nighttime flux and angular distribution of heavy nuclei were determined at a residual atmosphere of 25 g/cm^2. The values are compared to those from a daytime flight at the same altitude. The vertical flux at night is lower than the daytime flux by a factor of two to three. The rate of "star" production at night does not seem significantly different from the daytime rate. A recorder which worked for only part of the flight showed that the load was fortuitously oriented for at least one-fourth of the time at altitude. At large zenith angles the heavy nuclei flux shows an azimuthal asymmetry far beyond any expected statistical fluctuations.

* This work has been supported in part by the ONR.

F4. Preliminary Results of a Cloud Chamber Study of the Cosmic Radiation at an Altitude of 90,000 Feet.* R. RONALD RAU AND G. G. HARRIS, *Princeton University.*—A series of balloon flights have been made in which a Wilson cloud chamber was sent to an altitude of 90,000 feet. The balloons were the single cell plastic Project Skyhook type made available by the ONR. The cloud chamber was expanded at one minute intervals. The measured sensitive time of the chamber was 0.2 second. The chamber contained three plates, each 1 cm thick. During three flights the top plate was beryllium and the two lower ones were lead. During one flight all three plates were lead. A total of 1500 pictures were obtained. Preliminary results will be presented on two types of events: (a) events produced in beryllium by ionizing and non-ionizing radiations; (b) events designated as "sprays" by Oppenheimer and Ney.[1]

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

[1] F. Oppenheimer and E. P. Ney, Phys. Rev. **76**, 1418 (1949).

F5. Absorption Measurements on Cosmic-Ray Particles Producing Nuclear Interactions at 10,600 Feet.* R. H. REDIKER AND H. S. BRIDGE.—The paper describes the results of an experiment designed to measure the *absorption* and the *collision* mean free paths in lead and carbon of ionizing cosmic-ray particles capable of producing different kinds of nuclear interactions. The detector consisted of a lead-shielded ionization chamber and of several trays of Geiger-Mueller tubes. The separation between the absorption and the collision mean free paths was achieved by investigating whether the particle responsible for the nuclear interaction came out of the absorber alone or accompanied by other particles. If one considers nuclear interactions in which penetrating particles are produced one finds that: (a) the absorption mean free path of the producing radiation is approximately the same in gram per cm^2 for lead and carbon ($\sim$500 g/cm^2); (b) the collision mean free path is, however, greater in lead ($\sim$300 g/cm^2) than in carbon ($\sim$120 g/cm^2) in approximate inverse-relation to geometric cross section; (c) the absorption mean free path in carbon is approximately four times the absorption mean free path in air. The last result suggests that some of the nuclear interactions under the carbon absorber are due to π-mesons produced in the carbon.

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

F6. Analysis of the Cosmic Radiation at 3.4 Kilometers into Its Proton and Meson Components.* CHARLES E. MILLER, JOSEPH E. HENDERSON, DAVID S. POTTER, AND JAY TODD, *University of Washington.*—In previous work of this laboratory a momentum spectrum of the meson plus proton component of the cosmic radiation at 3.4 kilometers was obtained through a magnetic (8000 gauss) cloud-chamber analysis. Electrons were separated from the heavier particles through shower formation while the later were partially separated into protons and mesons through the increased density of the proton tracks of lower energy. Because of uncertainties and limitations to the ionization density criterion for protons an improved method of analysis has been employed. In this an arrangement of Geiger counters and absorbers was used to photograph selectively tracks of those non-shower producing particles lying in definite range intervals. Range intervals of 0–5, 5–15 and 15–25 cm of lead were used. In each case a plot of the momentum distribu-

tion of negative particles shows a single maximum at the momentum to be expected for mesons lying in the range interval selected. The distributions for positive particles show a second maximum at the momentum value to be expected for protons. It is interesting to note that, at this altitude, of those particles stopping in 5 cm of lead the number of protons is well in excess of the number of mesons.

* This work supported by the joint program of ONR and AEC.
** A division of the Department of Physics.

F7. On the Zenith Angle and Energy Dependence of Mesons at Sea Level.* JACOB L. ZAR AND M. H. SHAMOS, *New York University.*—Delayed coincidences have been observed with a telescope having threefold coincidence trays, with provision for the insertion of lead and iron moderators, a graphite absorber, an anti-coincidence tray, and side counters to detect decay electrons from the graphite. The apparatus tilts in the zenith direction and has an effective angular resolution of $\pm 7.3°$. The zenith dependence of mesons as determined by their characteristic decay was fitted by $I(\theta)=I(0)\cos^n\theta$; in which n, as determined for incident meson energies of 235, 550, and 890 Mev, was respectively 3.2, 2.3, and 2.0. Coincidence and anti-coincidence determinations of n gave values close to 2.0 and 3.0 respectively over the same energies. This work extends the measurements of Greisen[1] and Kraushaar[2] to higher energies. The results are in agreement in the region where comparisons can be made.

* Assisted by the joint program of the ONR and AEC, and by the Research Corporation.
[1] K. Greisen, Phys. Rev. **61**, 212 (1942).
[2] W. L. Kraushaar, Phys. Rev. **76**, 1045 (1949).

F8. Latitude Dependence of Atmospheric Neutrons at High Altitudes.* W. P. STAKER AND W. O. DAVIS,** *New York University.*—Atmospheric neutrons associated with the cosmic radiation have been measured to high altitudes at 30.4°N and 54.7°N geomagnetic latitudes using balloon-borne equipment. A system using one BF_3 counter enriched in the B^{10} isotope to 96 percent of the boron present and another counter depleted in the B^{10} isotope to 10 percent was developed. This method allows the calculation of the density of all neutrons in the energy range activating a BF_3 proportional counter. With similar physical characteristics, the counters can be assumed to contain identical star-producing materials, so it can be assumed that statistically the background will be the same for each counter. A maximum for the neutron density was found at approximately 100 g/cm² at 54.7°N and 120 g/cm² at 30.4°N. The relative counting rates at these two latitudes were about 3 to 1 at the maximum which is in good agreement with the data obtained at lower altitudes by Simpson[1] and Yuan.[2]

* Assisted by joint program of ONR and AEC.
** Major, USAF, now assigned to USAF Special Weapons Command, Kirtland AFB, Albuquerque, New Mexico.
[1] J. A. Simpson, Phys. Rev. **73**, 1389 (1948).
[2] L. C. L. Yuan, Phys. Rev. **76**, 1267 (1949).

F9. Measurements on Cosmic Radiation Far Underground. LOWELL M. BOLLINGER, *Cornell University.*—Properties of cosmic radiation in a salt mine at depths of approximately 1150, 1500, and 1790 meters water equivalent have been measured by means of a G-M counter hodoscope. The absolute vertical intensity and the angular distribution were measured at all three depths for the hard component. At 1790 m.w.e. the vertical intensity and angular distribution of the soft component were measured. Secondary events initiated both in the salt roof and in the lead of the apparatus by penetrating particles were recorded by the hodoscope. There are many events in which two counters are discharged simultaneously without a third counter being discharged. The ratio of the number of these twofold events relative to the single counter rate was measured for the natural radiation and for several γ-ray sources. The results support the view that the background twofold rate is caused by local γ-radiation.

F10. Cloud Chamber Triggered by Internal Scintillation Counter.* R. W. WILLIAMS, L. M. SPETNER, W. L. KRAUSHAAR, H. W. J. COURANT, *M.I.T.*—A magnet cloud chamber has been constructed which contains the fluorescent crystal of a scintillation counter, for observations on cosmic rays. The cloud chamber is $11\frac{1}{2}$ in. i.d., $3\frac{1}{2}$ in. deep, and is supported between the poles of an electromagnet whose field, at 43 kilowatts, is 11,000 gauss. The 1 in.×3 in.×4 in. napthalene crystal is mounted approximately in the center of the cloud chamber, with the 3 in. edge parallel to the cloud chamber axis. Two 1 in. diameter quartz rods, one abutting against either free edge of the crystal, guide the fluorescent radiation out to regions of weak field, where it falls on RCA 5819 photomultipliers in heavy magnetic shields. The crystal is wrapped with aluminum foil and sealed with Vinylite tape. The degree of internal reflection in this system is such that coincidences between the photomultipliers are observed with nearly 100 percent efficiency for particles of minimum ionization passing anywhere through the crystal. The cloud chamber can be triggered whenever either a coincidence between pulses of more than a given size occurs or a coincidence between pulses is followed, within 5 microseconds, by another coincidence. Representative photographs of cosmic-ray events will be shown.

* This paper is supported in part by the joint program of the ONR and the AEC.

F11. The Emulsion Chamber—A New Photographic Tool for the Study of Ionizing Particle Tracks. HERMAN YAGODA, *National Institutes of Health.*—The processing of thick (400 to 600 micron) nuclear emulsion plates is slow and is attendant with dangers of stripping or cracking during prolonged cosmic-ray exposures. Spurious curvature of tracks are also introduced as a result of uneven drying of the residual gelatin. To overcome these difficulties, and to extend the thickness of the recording medium to 2 mm, a departure has been made from the traditional glass coated plate: A concentrated AgBr emulsion is melted at 40° in a stainless steel cup measuring 5 cm in diameter and 0.5 cm high. After setting and dehydration an emulsion casting about 2 mm thick results. This is clamped between Lucite or lead plates to prevent buckling, and is thus exposed. Development and fixation are comparatively rapid (30 hours). During washing the gelatin swells to about 6 cm by 0.5 cm, but is brought back to its original diameter by gradual dehydration with a series of graded alcohols (1). The circular, uniform, emulsion casting minimizes track distortion and the exceptional thickness of the medium increases the probability of detecting double stars, and recording the termination point of fast particles. Preliminary results on a casting weighing 10 grams, exposed to cosmic radiation at Climax, Colorado, will be described.

[1] H. Yagoda, *Radioactive Measurements with Nuclear Emulsions* (John Wiley and Sons, Inc., New York, 1949), p. 53.

Invited Paper

F12. Gamma-Rays from Nuclear Collisions. HERBERT YORK, *University of California, Berkeley.*

THURSDAY AFTERNOON AT 2:15

Departmental Auditorium

(M. A. TUVE presiding)

Apparatus of Nuclear Physics

G1. Ring Focusing in a Thin Lens Magnetic Spectrometer. W. W. PRATT, F. I. BOLEY,* AND R. T. NICHOLS, *Iowa State College.*†—The baffle system of a thin lens beta-ray spectrometer[1] has been modified to make use of ring focusing.[2] The region of ring focusing was located by means of photographic films placed in the spectrometer at various axial positions with the plane of the film perpendicular to the spectrometer axis. Ring images on these films, due to a monoenergetic source of electrons, mapped out the electron beam. An annular baffle was inserted in the spectrometer to make use of the constriction observed in the beam. Using a Geiger counter aperture large enough to admit all electrons passing through the annulus, it was found that for a line half-width of two percent the transmission with this type of focusing is twice that obtained with axial focusing.

* Socony-Vacuum Corporation, Research Fellow.
† This work was performed at the Ames Laboratory of the AEC.
[1] Jensen, Laslett, and Pratt, Phys. Rev. **75**, 458 (1949).
[2] Keller, Koenigsberg, and Paskin, Phys. Rev. **76**, 454 (1949).

G2. A Gamma-Ray Spectrometer Based on the Compton Effect.* J. A. MCINTYRE AND R. HOFSTADTER, *Princeton University.*—Using NaI(Tl) scintillation counters a rough spectrometer for determining gamma-ray energies has been developed. The operation depends on a measurement in one of the crystals of the energy of the recoil electron in the Compton effect. The energy has been measured as a pulse height with a single channel discriminator. The scattered gamma-ray corresponding to the recoil electron studied has been utilized as a coincidence gate to select the time when the discriminator is active. Two different arrangements have been examined in which the gate corresponds to forward and backward scattered gamma-rays. With this spectrometer the 1.17- and 1.33-Mev lines of Co^{60} have been resolved. Other cases will be discussed.

* This work received partial support from the U. S. Army Signal Corps and the joint program of the AEC and ONR.

G3. A Small Electrostatic Generator.* D. I. COOPER, D. H. FRISCH, C. L. STORRS, JR., AND C. J. STRUMSKI, *M.I.T.*—A 1-Mv Van de Graaff generator has been built primarily for low energy $p-p$ and for $n-p$ scattering experiments. Salient characteristics are: (1) A simple d.c. arc in an axial magnetic field[1] (Alnico) provides more total current than the charging current and accelerating tube can handle at present, at tube pressures of $\sim 10^{-5}$ mm. No pre-acceleration is used. (2) The two identical accelerating tubes are made of high dielectric constant ($\kappa = 9$), locally fabricated statite sections, 8 in. mean i.d., 9 in. mean o.d., 2 in. high, and are assembled with the $\frac{1}{16}$ radian inside slope arranged so as to repel electrons from the surface. The thin flat electrodes are 7 in. i.d. The focusing electrode next to the high voltage terminal is a 1 in. i.d. quasi-doughnut. At present the beam induces frequent tube breakdowns, especially when in poor focus. (3) A 600-kv unanalyzed beam makes a white hot spot on Vykor glass. (4) The other parallel accelerating tube is to have in it a control beam of electrons, operating on the signal from a time-of-flight analysis of the mass two ion beam.

* Assisted by the joint program of the ONR and AEC.
[1] Bailey, Drukey, and Oppenheimer, Rev. Sci. Inst. **20**, 189 (1949).

G4. Radiofrequency Ion Source for Electrostatic Generator.* K. R. MORE, R. H. CHOW, J. K. KINNEAR, AND S. B. WOODS, *University of British Columbia.*—Ion sources excited by radiofrequency electrodeless discharges have been described by Bayly and Ward,[1] Thonemann[2] and others. A proton source of this type has been constructed for the University of British Columbia electrostatic generator. Positive ions of hydrogen are formed in a low pressure electrodeless discharge in a Pyrex tube. Radiofrequency power, at a frequency of 200 Mc/sec., is fed into the discharge tube by means of external electrodes. An axial magnetic field reduces the diffusion of ions to the tube walls. An electric field maintained between a small tungsten anode and the exit canal accelerates and focuses the ions into the canal. The emerging ions are focused and accelerated to 50 kv before entering the main accelerating column of the generator. Differential pumping of the ion source is provided. On a test system, total beam currents of 800 μa have been achieved with a gas consumption of 15 cc per hr. Magnetic analysis showed that the beam consists of 45 percent protons.

* Supported by a grant-in-aid from the National Research Council of Canada.
[1] Bayly and Ward, Can. J. Research **26**, 69 (1948).
[2] Thonemann, Moffatt, Roaf, and Sanders, Proc. Phys. Soc. **61**, 483 (1948).

G5. Performance of 300-Mev Betatron.* G. D. ADAMS, D. W. KERST, AND C. S. ROBINSON, *University of Illinois.*—The first trail of the 300-Mev betatron was made February 15, 1950, and yield was observed immediately. The first measurements at 300 Mev showed 15,000 r per hr. at one meter in 0.125-in. Pb with 6 pps. and about 40-kev injection. Calculated orbital radiation loss is nine percent at 96.6 percent of peak field for 300 Mev and is compensated by a flux pulse. Field test results were similar to those for the 80-Mev model.[1] An orbit is established within 12 μsec. of the start of the flux through the 275-ton yoke. The azimuthal variation of field at injection is less than ± 0.13 gauss except at the six field magnet junctions where lags 5° wide and as much as 0.5 gauss exist, and except at the coil terminals where the field is 0.2 gauss early. Radial field at the orbit is less than 0.13 gauss except at the junctions. The residual field between 300-Mev pulses is 4.5 gausses. It is uniform within ± 0.15 gauss.

* This work assisted in part by the joint program of the ONR and AEC.
[1] Kerst, Adams, Koch, and Robinson, Phys. Rev. **75**, 330 (1949). Also "An 80-Mev model of a 300-Mev betatron," Rev. Sci. Inst. (to be published).

G6. Operation of the M.I.T. 350-Mev Electron Synchrotron.* I. A. GETTING, J. S. CLARK, J. E. THOMAS, JR., I. G. SWOPE, AND M. L. SANDS, *M.I.T.*—A combination of the betatron and synchrotron principles has been incorporated in the design of a ring type magnet, weighing approximately 55 tons, with a nominal tube radius of 1 meter. The machine operates on single cycle excitation with a peak voltage of 15,000 volts and a peak current of 4500 amp. Betatron operation is used to 4 Mev. Synchrotron operation employs a self-excited, class *C* oscillator feeding a quarter-wave line cavity which constitutes one section of the accelerator tube. The entire tube is made of slip-cast steatite. The output of the machine at 350 Mev is approximately 100 mr per pulse measured two meters from the target with a Victoreen thimble chamber embedded in $\frac{1}{4}$ in. of lead.

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

G7. Electron Injection Gun for the M.I.T. 350-Mev Synchrotron.* ORVILLE STONE, *M.I.T.*—An electron gun employing a sintered cathode has been developed for the injection of electrons in the synchrotron. The cathode material, developed by the Raytheon Manufacturing Company, consists of thoria (75 percent) and molybdenum (25 percent), and may be sintered in any desired shape. With proper shaping much better focusing properties may be obtained than with coiled filaments. Other advantages are great rigidity, high emission, and long life, even when exposed periodically to air.

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

G8. Design of Magnet Ends and Straight Sections for a Racetrack Synchrotron.* G. B. BEARD, J. L. LEVY, W. A. NIERENBERG, AND R. W. PIDD, *University of Michigan.*—In a racetrack type synchrotron, undesirable end effects in the transition region between a magnetic quadrant and a field-free straight section are caused by the leakage flux and by out-of-phase field components due to eddy currents in the end laminations. To determine their extent at injection time, when they are especially harmful, mappings of the field were obtained under various conditions by local measurements of the field amplitude and the phase shift relative to the main field. These end effects can be varied considerably by shaping the magnet ends and using different materials, particularly iron, in the straight sections. Data are presented on the use of iron straight sections to control stray magnetic fields and eddy current effects. A special peaking strip arrangement was devised to meet the required precision for these measurements.

* This work was supported by the Navy Bureau of Ordnance.

G9. Optimum Parameters for Particle Acceleration by TM 010 Cylindrical Cavities. B. L. MILLER, *Bartol Research Foundation.*—Several linear accelerator projects make use of cylindrical cavities operating in the TM 010 mode. The energy imparted to the beam is somewhat increased by using less than a full half-cycle, because in the shorter cavity a higher field is attained for the same power input. For particles injected at velocity c, the cavity length for maximum acceleration is 0.44λ and the optimum injection angle 11° after the zero field phase independent of the r-f power level.[1] For initial velocities less than c, the optimum cavity length and injection angle depend both on the injection velocity and the r-f power available. Calculations of these optimum parameters have been made in the low energy case, for small relativistic correction, and in the far relativistic region where most of the orbit is traversed near velocity c. Because the optimum values do not vary widely (e.g., injection angle always less than 11°), they can be estimated, from the above calculations, for the intermediate region.

[1] W. Graffunder, Helv. Phys. Acta **22**. 239 (1949).

G10. 200-kv Accelerator with Gas Recovery System. E. ALMQVIST, K. W. ALLEN, J. T. DEWAN, T. P. PEPPER, AND J. H. SANDERS, *Chalk River Laboratory.*—A 200-kv accelerator has been built incorporating a gas recovery system. A radio-frequency ion source[1] with a $\frac{1}{16}$-in. diameter exit canal produces at the target a 200-μA beam for a gas consumption of 8 cc per hour (hydrogen). The beam is focused through a second canal into the accelerating tube; the gas flowing out of the ion source is pumped by mercury diffusion pumps into a suitable reservoir. More than 95 percent of the gas is recovered by this differential pumping system. Since very little gas enters the accelerating tube, the pressure in it is less than 2×10^{-5} mm with the beam on. This results in a steady well-focused beam. When hydrogen is to be recovered the gas issuing from the mercury pumps is absorbed in a spongy uranium reservoir.[2] It may be recovered quantitatively by heating the uranium hydride to 430°C.[3]

[1] Thonemann *et al.*, Proc. Phys. Soc. **61**, 483 (1948).
[2] Taschek *et al.*, Phys. Rev. **75**, 1361 (1948).
[3] Spedding *et al.*, Nucleonics **4**, No. 1 (1949).

G11. A New Method of Radioactivity Measurement.* W. GROSS AND G. FAILLA, *Columbia University.*—The method is based on the measurement of the charge carried away from the radioactive source by the beta-rays. The source consists of a thin deposit of the active material at the center of a thick conducting plate. Secondary electron effects are eliminated by "covering" the source plate with an identical but non-active plate parallel and very close thereto, and by the use of a weak magnetic field which curls back the very low energy electrons. Measurements are carried out in an evacuated chamber to remove all ionization effects. The method is independent of beta-ray energy and is more direct than the usual G-M counter methods. To express the results in disintegrations per second (or curies) it is not necessary to know the complete disintegration scheme of the isotope. Beta- plus gamma-ray emitters can also be measured. The apparatus is simple, small, and reliable. Measurements of P^{32}, S^{35}, and I^{131} show very close agreement with the results obtained by another absolute method developed in this laboratory.

* Performed under AEC contract.

G12. Electron Track Grain Densities in Nuclear Emulsions. DALE R. CORSON AND MARGARET R. KECK, *Cornell University.*—We have studied the grain density of electron tracks in electron-sensitive Ilford G-5 nuclear emulsions in an attempt to observe the increase of grain density with energy which might be expected at energies above that of minimum ionization. Using magnetically deflected pair-produced electrons from synchrotron radiation, we have recorded tracks of 180-Mev electrons at right angles to 40-Mev electrons on a single plate together with 10-Mev cyclotron produced pair electrons. An energy is assigned to a track according to the direction of the track and to its multiple scattering. The observed grain density on a single plate for all three energies is 36.6 ± 0.6 grains per 100 microns. A more refined experiment is necessary to detect the increase in grain density, if any, at high energies. There are significant differences, however, in grain density from plate to plate, probably depending on the temperature of exposure, development procedure, emulsion batch, etc. On different plates we have observed relativistic electron track densities as low as 25 and as high as 42 grains per 100 microns.

G13. The Measurement of Particle Energies with Scintillation Counters.* W. FRANZEN, R. PEELLE, AND R. SHERR, *Princeton University.*—The response of a scintillation counter to heavy particles has been investigated with respect to resolution and relationship of pulse height to energy. Protons from the Princeton cyclotron were scattered by a platinum foil into NaI, KI, and anthracene crystals mounted under good optical conditions on a RCA-5819 photo-multiplier tube. The incident proton energy was varied by interposing aluminum foils. Pulses were amplified by a Model 501 amplifier (rise time 0.15 μsec.; clipping time 5 μsec.) and analyzed by a single channel discriminator. Approximately Gaussian distributions having a width at half-maximum of three percent were obtained with NaI and KI. For these crystals, a plot of pulse height *vs.* energy yields a straight line which passes through the origin if the initial proton energy is taken to be 17.1 Mev. An air range measurement yielded 16.9 Mev for this energy. For anthracene, the pulse height per Mev decreases markedly with decreasing proton energy. For comparison, the relative pulse amplitudes (per Mev) were measured for 626-Kev electrons, 17-Mev protons, and 5.3-Mev alpha-particles, and were found

to be approximately 4.6:4.6:3.4 for NaI, 0.9:1.0:1.0 for KI, and 2.9:1.8:0.3 for anthracene.

* Supported by the ONR and AEC.

G14. A Versatile Delayed Coincidence Circuit.* W. R. KONNEKER, S. DEBENEDETTI,† AND F. K. MCGOWAN,‡ *Washington University.*—A versatile survey instrument has been constructed for the purpose of investigating short-lived isomeric states over a wide range of half-lives. The instrument consists essentially of a coincidence circuit with provision for introducing various amounts of time delay, together with a gate circuit arranged so that only pulses of sufficient amplitude to give positive operation of the coincidence circuit are counted. The gate circuit, when used with scintillation counters, suppresses random time fluctuations due to variations in pulse height. The incident pulses are applied to a pair of multivibrators, and the return pulse, rather than the leading edge, actuates the coincidence circuit. Delay may thus be introduced by varying the time constant of the multivibrator feed-back circuit. Provision is made for matching the coincidence circuit resolving time to the time delay in order to maintain optimum counting rate consistent with the attainable accuracy. Half-lives can be measured over the range 0.05 μsec. to 1 μsec. Results will be reported on about 30 isotopes that have been investigated to date.

* Assisted by the joint program of the ONR and AEC.
† Now at Carnegie Institute of Technology, Pittsburgh, Pennsylvania
‡ Oak Ridge National Laboratory, Oak Ridge, Tennessee.

THURSDAY AFTERNOON AT 2:15

Lisner Auditorium

(J. A. BEARDEN presiding)

Invited Paper

H1. High Precision Methods for Absolute Determination of Nuclear Energy Levels. J. W. M. DUMOND, *California Institute of Technology.* (25 min.)

X-Rays; Cryogenics

H2. Pair Spectrometer for High Energy X-Rays.* J. W. DEWIRE, A. ASHKIN, AND L. A. BEACH, *Cornell University.*—An electron pair spectrometer has been constructed for studies using the x-ray beam from the Cornell synchrotron. The x-rays pass through a slit system and a clearing magnetic field before striking the thin pair-forming target in the gap of the spectrometer magnet. The pairs created in the target are detected by 18 groups of Geiger-Müller counters placed symmetrically on either side of the magnet. Pulses from the counters are fed into an electronic circuit in which coincidences corresponding to the various x-ray energies are recorded in appropriate output channels. The circuit is designed to reject ambiguous events involving triple coincidences. The electron orbits in the spectrometer magnet were determined by suspending in the magnetic field a flexible wire carrying a current. The shape of the wire describes the orbit of an electron whose momentum is given by the ratio of the tension to the current in the wire. Preliminary measurements have been made on absorption of 210-Mev x-rays in various materials. Results of these experiments will be given.

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

H3. Angular Distribution and Intensity of 70-Mev X-Rays from Various Targets.* G. C. BALDWIN, F. I. BOLEY, AND H. C. POLLOCK, *General Electric Company.*—Measurements have been made of the angular distribution and intensity of x-radiation generated by 70-Mev electrons in Al, Cu, Mo, W, and Pt targets of various thicknesses. The synchrotron beam was alternately contracted and expanded respectively to an inner tungsten reference target and to an outer target carried by a mechanism with which the targets could be changed without breaking the vacuum. Two arrays of small ionization chambers were used to measure the intensity distribution in each of the resulting x-ray beams. The results are compared with theoretical beam shapes and intensities calculated from multiple scattering and bremsstrahlung theory.[1] Excellent agreement with theory is found for Al and Cu targets for thicknesses of the order of 10^{-2} radiation lengths. Similar targets of higher atomic number show increasing deviations, indicating that multiple scattering and radiation in these elements are less than predicted from theory. Aluminum targets of thickness below 10^{-3} radiation units show indication of multiple transits by the electron beam.

* Supported by ONR contract.
[1] L. I. Schiff, Phys. Rev. **70**, 87 (1946).

H4. A Versatile Precision Bent Crystal Focusing Vacuum X-Ray Spectrometer.* E. L. JOSSEM AND L. G. PARRATT, *Cornell University.*—A focusing crystal x-ray spectrometer has been constructed for investigation of solid state problems. The instrument features high luminosity and high, adjustable, resolving power as well as versatility and precision. The x-ray source, crystal and detector are in a common vacuum envelope evacuated to $\sim 10^{-6}$ mm Hg, permitting study of long wave-lengths. Either transmission or surface reflection may be used and the shift from one method to the other can be made quickly and easily. This allows use of a variety of crystals and provides a very large wave-length range. The crystal, bent to a radius of 50 cm, is fixed and the source and detector are moved to vary the wave-length region studied. The source and detector positions can be simply interchanged for measurement of double Bragg angles. A precision worm-and-gear measures Bragg angles to about ±0.1 second of arc. Both photographic and electrical recording of x-ray intensity are used to provide the supplementary advantages of the two methods and a direct comparison between their results. Preliminary results obtained with this spectrometer will be reported.

* Work supported in part by the ONR.

H5. Interface Absorption by Evaporated Aluminum Films at 130 Angstroms. E. M. PELL AND D. H. TOMBOULIAN, *Cornell University.*—Absorption experiments in the soft x-ray region conducted by Skinner and Johnston[1,2] on Li, Mg, and Al have indicated the presence of an intense and relatively sharp band superimposed on the absorption curve of the

...etallic lattice itself. In the case of Al at least, this band is ...missing from the absorption curves obtained in the neighborhood of the K-edge.[3] The present investigation confirms the results previously obtained by Johnston in the case of Al and reveals the origin of the additional absorption band. Evidence obtained from recent measurements show that the sharp absorption dip arises from the interface region of about 500A in thickness lying between the evaporated metal and the organic substrate. The presence of the band does not seem to depend on the choice of substrate materials such as celluloid, Zapon, or polystyrene. However, thin Al absorbers free from backing materials do not exhibit the narrow absorption observed in the case of absorbers prepared by evaporation. The research was supported by the ONR.

[1] H. W. B. Skinner and J. E. Johnston, Proc. Roy. Soc. London, **161**, 420 (1937).
[2] J. E. Johnston, Proc. Camb. Phil. Soc. **35**, 108 (1939).
[3] Munier, Bearden, and Shaw, Phys. Rev. **58**, 537 (1940).

H6. Average Electron Density Measurements by Low Angle X-Ray Scattering.* H. M. BARTON, JR., *Phillips Petroleum Company.*—According to Guinier[1] the low angle x-ray scattering of particles should disappear when they are immersed in a fluid of equal electron density. This furnishes a way of measuring the electron density of powders, providing a suitable impregnating fluid can be found. Experiments of this type have been carried out with carbon black. A method of calculating the low angle scattering coefficient defined by Warren is given for impregnated samples. Total low angle scattering measurements were made using a double crystal spectrometer and Geiger counter. No liquid was found that would give complete matching but approximate matching was obtained with phosphoric acid solution. The data extrapolate to show an electron density of $1.1N \pm 0.1N$ where N = Avogadro's number. This compares with a value of $0.99N$ as calculated from the helium immersion mass density measurement on the same sample.

* Work carried out at the Polytechnic Institute of Brooklyn.
[1] A. Guinier, J. Chim. Phys. **40**, 133 (1940).

H7. Resistance Minima in Metals at Low Temperatures.* M. P. GARFUNKEL, F. G. DUNNINGTON, AND B. SERIN, *Rutgers University.*—The work of Meissner[1] indicated that magnesium and aluminum might have minima in resistance at low temperatures. Thus resistance measurements were made on polycrystalline wires of these substances in the liquid helium temperature range. No minimum was found in aluminum. Magnesium showed a pronounced increase in resistance with decreasing temperature, below 4.2°K. The magnesium wire was 0.028 in. in diameter and 99.7 percent pure, the major impurities being aluminum, iron and silicon. Two polycrystalline samples of gold of different purity had resistance minima. The temperatures of the minima depended on the residual resistances in exact agreement with the work of de Haas and van den Berg.[2]

* This work has been supported by the ONR, by the Research Corporation, by the Rutgers University Research Council, and by the Radio Corporation of America.
[1] W. Meissner and B. Voight, Ann. d. Physik **7**, 761 (1930).
[2] W. J. de Haas and G. J. van den Berg, Leiden Comm. No. 241 d (1936).

H8. Experiment with Alternating Currents on Tin Superconductors. II.* B. SERIN, C. A. REYNOLDS, AND M. P. GARFUNKEL, *Rutgers University.*—The measurements reported last year[1] in which a.c. and d.c. are superimposed on a superconductor, and the average e.m.f. is measured as a function of the amplitude of the a.c., have been extended. The work was done with a variety of samples, differing in normal resistivity and diameter. The resistivity was changed by adding small quantities of lead to pure tin. The increase in average e.m.f. for high frequency a.c. over what is predicted by the Silsbee effect was again observed. This deviation increases roughly linearly with increasing values of ρ = (radius ÷ a.c. skin depth in normal conductor), until $\rho = 5$ and then begins to decrease. These results indicate that experiments of this type are unsatisfactory for determining the relaxation time for the transition from the superconducting to the normal state.[2]

* This work has been supported by the ONR, by the Research Corporation, by the Rutgers University Research Council, and by the Radio Corporation of America.
[1] Serin, Feldmeier, and Garfunkel, Abstract No. C 7, Phys. Rev. **76**, 167 (1949).
[2] Lasarev, Galkin, and Khotkevich, C.R. Acad. Sci. U.R.S.S. **55**, 805 (1947).

H9. The Rollin Film Creep Rate in He^4 and He^3–He^4 Mixture. HENRY A. FAIRBANK, ERNEST A. LYNTON, AND C. T. LANE, *Yale University.**—The previously used technique of Fairbank and Lane[1] for determining the flow rate of the Rollin Film has been applied to further study of He^4 and mixtures of He^3–He^4. The creep rate with pure He^4 was found to rise from zero at the λ-point to about 20×10^{-5} cm³/cm-sec. near 1.6°K. Below this temperature it remained nearly constant over a temperature range varying with the size of the leak, and then rose abruptly, reaching in some cases values as high as 50×10^{-5} cm³/cm-sec. at 1.2°K. Elaborate precautions ensured that this was not a contamination effect. With mixtures of He^3 and He^4 having λ-points in the vicinity of 2.0°K the creep rate was considerably lower, being about one-third to one-half the value found for pure He^4.

* Assisted by the ONR.
[1] H. A. Fairbank and C. T. Lane, Phys. Rev. **76**, 1209 (1949).

H10. Bloch's Theorem and Superconductivity. M. DRESDEN AND J. DELORD, *University of Kansas.*—The attempts to explain superconductivity in terms of a lowest state which carries a finite current, have been discredited to some extent[1] in view of a general result of Bloch, which asserts, that for a quantum mechanical system the lowest energy state is one of zero linear momentum. More precisely the quantum mechanical average of the linear momentum vanishes, thus leading to a zero total current. Bloch's result can be generalized considerably, one can prove that in the lowest state the quantum mechanical average of the linear momentum of every electron vanishes. A simple extension of Bloch's method, yields an infinite sequence of similar though somewhat more complicated results. It should be remarked that these results suffer essential modifications when exchange interactions are taken into account. However, the currents dealt with in superconductivity are not the quantum mechanical averages to which Bloch's results refer. One should distinguish the quantum average of the probability current, a locally, microscopically defined electric current,[2] a macroscopic average of this last current. Consequently Bloch's result does not imply that this latter current, necessarily vanishes.

[1] B. Bohm, Phys. Rev. **75**, 502 (1949).
[2] F. London, Phys. Rev. **74**, 562 (1948).

H11. Equation of the Magnetic Threshold Curve for Indium. G. PRESTON BURNS, *Mary Washington College of the University of Virginia.*—On the basis of the Gorter-Casimir expression[1] for the jump in atomic heat of a superconductor at its transition temperature and the assumption[2] that the specific heat of superconducting indium varies as T^4 it has been shown that the magnetic threshold curve for indium is given by

$$H=[H_0/(18\gamma_N T_c^2+D_N T_c^4)](18\gamma_N T_c^2+D_N T_c^4 - 30\gamma_N T^2-5D_N T^4+3KT^5)^{\frac{1}{2}},$$

where

$$T_c=1/9K\{[1458K^2\gamma_N+64D_N^3 +54K(729K^2\gamma_N^2+64\gamma_N D_N^3)^{\frac{1}{2}}]^{\frac{1}{3}} +[1458K^2\gamma_N+64D_N^3 -54K(729K^2\gamma_N^2+64\gamma_N D_N^3)^{\frac{1}{2}}]^{\frac{1}{3}}+4D_N\}.$$

K is the constant relating the specific heat of the superconducting body to T^4 and other symbols are as defined previously.[3]

[1] C. J. Gorter and H. Casimir, Physica **1**, 306 (1934).
[2] A. D. Misener, Proc. Roy. Soc. **174**, 266 (1940).
[3] G. P. Burns, Phys. Rev. **76**, 999 (1949).

H12. Superconducting Properties of Columbium. D. B. Cook, M. W. Zemansky, and H. A. Boorse, *Columbia University.*—Various values of the superconducting temperature T_0 of columbium have been reported, ranging from 5.09° to 9.58°K; in addition transitions in magnetic fields have been observed in the helium temperature range. In view of the uncertainty of T_0 and the absence of magnetic field data above 4.2°K, we have measured transitions between 5° and 9° on analyzed columbium of the highest purity obtainable (99.8 percent or better). Changes from the superconducting to the normal state were observed by an a.c. induction method. Comparison measurements were made on columbium containing 0.4 percent tantalum as determined by neutron studies. Samples of the two materials, annealed and outgased at 1000°C, gave identical results. The $H-T$ curve may be represented approximately by the usual parabolic relation $H=H_0(1-T^2/T_0^2)$ with $H_0=7280$ oerst and $T_0=9.0$°K. This value of H_0 is more than twice as large as that corresponding to the earlier measurements in the helium range. These experiments were performed on cylinders 5 cm long and 2 mm in diameter in transverse fields and therefore yielded values of the ratio $\rho=H_i/H_f$, where H_i is the field necessary to initiate an $s-n$ transition and H_f is the field necessary to complete it. Observed values of ρ, which were in the range 0.65 to 0.71, showed a slight temperature dependence similar to that observed on tin and mercury. Work supported in part by ONR.

H13. Thermal Rayleigh Disk in Liquid Helium II. John R. Pellam, *National Bureau of Standards.*—The Rayleigh Disk[1] is employed to detect second sound mechanically and to examine the hydrodynamics of the internal convection of liquid helium II. A small disk-shaped mirror suspended at 45° to the wave propagation axis of a second sound system experiences a torque under conditions of resonance, thereby deflecting a light beam. The operation of this Rayleigh Disk depends upon its response to *presence* of particle velocity irrespective of sign (being a velocity squared effect) so that the net torque is the sum of the contributions by the two separate fluid components. Thus, whereas mechanical detectors of the microphone class do not recognize the internal convection peculiar to second sound, the present device (detecting *kinetic energy density*) resolves this internal motion. This experiment is regarded as an added confirmation of the two-fluid hypothesis for liquid helium II. Measurements of the wave velocity of second sound agree with previous determinations, and are being extended in the temperature region near the λ-point. The variation of observed torque with temperature is hoped to provide information on the relative roles (the hydrodynamics) of the normal fluid and the superfluid in their respective interactions with the disk.

[1] Lord Rayleigh, *The Theory of Sound* (Dover Publications, New York, 1945), Vol. II, p. 44.

Thursday Afternoon at 2:15

National Academy

(W. F. Meggers presiding)

Invited Paper

I1. Isotope Shift in Atomic Spectra of Heavy Elements. Hans Kopfermann, *University of Goettingen.* (30 min.)

Atomic Spectroscopy

I2. The Spectrum of He^3 I. Mark Fred, Frank S. Tomkins, and James K. Brody, *Argonne National Laboratory.*—Helium isotope shifts previously reported[1] have been extended and the He^3 hyperfine structure partially resolved. The h.f.s. of the ^3S levels is inverted, indicating a negative nuclear magnetic moment as expected. The splitting of the $2\,^3S$ level is 0.221 ± 0.005 cm^{-1} which is slightly smaller than given by hydrogenic wave functions with Anerson's[2] value for the magnetic moment; higher ^3S levels have a splitting of about 0.216 cm^{-1}. The stronger h.f.s. components of transitions to the ^3P and ^3D levels are not resolved but the structure must be considered in evaluating the isotope shifts. Including contributions from reduced mass and coupling effects the predicted and observed shifts differ by $\sim$0.1 cm^{-1} in the sense that the He^3 ^3S terms are higher and the ^1S, ^3D, and ^1D terms lower than expected with respect to the ^3P and ^1P levels. In addition, the trend of the differences for successive D series members indicates an increase in the repulsion of the ^3D and ^1D terms near the crossing at $n=8$ due to the fact that the He^3 ^3D h.f.s. is larger than the He^4 ^3D find structure.

[1] Fred, Tomkins, and Brody, Phys. Rev. **75**, 1772 (1949).
[2] Herbert L. Anderson, Phys. Rev. **76**, 1460 (1949).

I3. On the Nuclear Spin of Mo^{95} and Mo^{97}. O. H. Arroe, *University of Wisconsin.**—In hyperfine structure studies with separated isotopes** of Mo^{95} and Mo^{97}, certain lines, including $4d_{5s}{}^5\,{}^7S_3-4d_{5p}{}^5\,{}^7P_{234}$ and $4d_{5s}{}^5\,{}^5S_2-4d_{5p}{}^5\,{}^5P_{123}$, show clearly that the nuclear spin of each of these isotopes is different from the value $\frac{1}{2}$ previously listed[1] as probable.

* Supported by Navy contract.
** Supplied by the Y-12 plant, Carbide and Carbon Chemicals Division, on AEC allocation.
[1] N. S. Grace and K. R. More, Phys. Rev. **45**, 166 (1934).

I4. The Isotope Shift in Pb II.* Felix E. Geiger, Jr., *University of Wisconsin.*—A new investigation of the isotope shift in PbII has been undertaken in the visible region of the spectrum with AEC allocated** lead samples enriched in the isotopes of Pb^{204} and Pb^{207} respectively. The ratio of the shift of Pb^{206} relative to Pb^{204} to the shift of Pb^{208} relative to Pb^{206}, i.e., $(\nu_{206}-\nu_{204})/(\nu_{208}-\nu_{206})=R$, has been measured for lines λ5608 $(7s\,{}^2S_{1/2}-7p\,{}^2P_{3/2})$, λ5544 $(7p\,{}^2P_{3/2}-7d\,{}^2D_{5/2})$, and λ5373 $(6s6p^2\,{}^4P_{5/2}-5f\,{}^2F_{7/2})$, and the following ratios have been obtained thus far: $R_{5506}=0.90$ (±0.01 limit of error), $R_{5544}=0.90$ (±0.05 limit of error). R_{5608} is in good agreement with results obtained earlier by Schüler and Jones.[1] Although

interconfiguration perturbations currently appear to make absolute determinations of the isotope shift virtually impossible, an attempt is being made to determine the shift in the $7s\ ^2S_{1/2}$ level previously reported to have no shift at all.[1]

* Work done under ONR contract.
** Produced by Carbide Carbon Chemicals Division, Y-12 Plant, Oak Ridge.
[1] Schüler and Jones, Zeits. f. Physik **75**, 563, 1932.

I5. Zeeman Effect in O_2.* A. F. HENRY, *Yale University.*—A general formula for the Zeeman levels in O_2 is derived. The calculation starts with a set of eigenfunctions corresponding to Hund's case (a); the external magnetic field and terms in the Hamiltonian leading to the rotational triplets are introduced as perturbations. The work proceeds in two stages. First eigenfunctions differing only in the value of Σ are combined. In the second stage three such combinations differing in the total angular momentum, J, are further combined. The energy levels which result from the last operation are in good agreement with the observations of Beringer and Castile.[1] Calculated line intensities are in tolerable agreement with preliminary measurements.

* This work was supported by the ONR.
[1] Robert Beringer and J. G. Castle, Jr., Phys. Rev. **75**, 1963 (1949).

I6. Spectroscopic and Extrapolated Ionization Potentials of Atoms and Ions. WOLFGANG FINKELNBURG, *Fort Belvoir.*—The accuracy and reliability of spectroscopic ionization potentials, particularly those of higher atomic ions, depends on the number of observed lines and the observability of combinations with the ground state. Therefore, interpolated or extrapolated values, if properly based on a sufficient number of reliable spectroscopic ionization potentials, may occasionally be more accurate than direct spectroscopic values with an insufficient basis. Consequently, there does not seem to be a reason to regard such extrapolated spectroscopic values more sceptically than so-called direct spectroscopic values based on an extrapolation from a small number of observed lines. The methods of interpolation and extrapolation of ionization potentials as presented in two recent Letters to the Editor (W. Finkelnburg and F. Stern, Phys. Rev. **77**, 303, 1950; W. Finkelnburg, Phys. Rev. **77**, 304, 1950) have been further extended and improved. The different available methods will be discussed with their inherent accuracy. 160 ionization potentials of the first 18 isoelectronic sequences have thus been calculated or corrected, making use of the direct spectroscopic values in C. E. Moore's book *Atomic Energy Levels.*

I7. Pressure Broadening of Spectral Lines and Frequency Modulation. HENRY MARGENAU AND STANLEY BLOOM, *Yale University.**—Under certain circumstances, the contour of a spectral line can be calculated by means of the so-called statistical theory, under others the impact theory is appropriate. Extreme conditions for the validity of either approximation are easily stated, but the manner in which the statistical distribution transforms itself into the impact distribution is difficult to investigate. We have chosen the solution of a well-known engineering problem, sinusoidal frequency modulation, as a simple instance of the transformation in question. The results to which it leads are physically meaningful and will be discussed in this paper. The "modulation index" determines the nature of the intensity distribution; if its value is large, statistical theory is applicable. Roughly, this index corresponds to the ratio of the maximum frequency shift during molecular impacts to the number of collisions per second. As for detail, however, the model is not sufficiently flexible to do justice to the line-broadening problem.

* Assisted by the ONR.

I8. A Coating Method Based on the Use of Electrically "Exploded" Wires. WILLIAM M. CONN, *Rockhurst College.*—Condensers of large capacitance are discharged through very thin wires, ribbons, or powdered metal in capillary tubes. Deposits are obtained which seem to be due to sputtering from the exploding wire and the cloud of disintegration products observed after the exposition. By exploding the wire in nitrogen or hydrogen metallic deposits are obtained on glass and other non-metallic objects, for example, as follows: Spark gaps 5 mm, length of wires 25 mm, diameter of wires 0.10 mm, pressure for silver 48 mm Hg, gold—140 mm, aluminum—350 mm. Deposits are of high reflectivity and good adherence; they may be used for partial mirrors for interferometer work, etc. The principal advantages of this method over well-known methods of coating—chemical deposition, spraying, cathode sputtering, and vaporizing—are the moderate low pressure and the short time required (10^{-5} to 10^{-6} second) for obtaining a layer on the object.

THURSDAY AFTERNOON AT 2:15

National Bureau of Standards

East Building Lecture Room

(R. M. BOZORTH presiding)

Ferroelectricity; Ferromagnetism; Electron Optics

J1. On Certain Matters Pertaining to Electrets. W. F. G. SWANN, *Bartol Research Foundation.*—Consider an electret of thickness L with surfaces perpendicular to the axis of x at $x=0$ and $x=L$, and polarized in the positive direction of that axis. Suppose that P_x decays with time through a factor $e^{-\alpha x}$ and that initially, as the result of the polarization and surface or volume charges, the potentials at $x=0$ and $x=L$ are V_0 and zero. Suppose the surfaces covered by foils joined by a resistance R which may be the internal resistance of the dielectric. Let C be the capacity. It results that if the disappearance of the charges is determined by Ohm's law, the variation of the potential V at $x=0$ *will be independent of the original distribution of charge.* Provided that V_0 is negative and that the time constant $1/\alpha$ is greater than RC, V will drop to zero in a time τ_1 of the order of RC. It will then rise to a positive maximum V_m in a time τ_2 and will finally decay to zero. Reasonable values of the quantities concerned are consistent with τ_1 being comparable with a day or two, τ_2 with a week, V_m of the order of 2000 volts with a decay to $\frac{1}{3}$ of this value in three years.

J2. Electronic Theory of Ferroelectrics. E. T. JAYNES AND E. P. WIGNER, *Princeton University.*—Ferroelectrics of the $BaTiO_3$ type occur, according to Matthias,[1] whenever an ion

with a closed shell is surrounded by an octahedron of oxygen ions of a certain size. There is considerable evidence[2] that spontaneous polarization in $BaTiO_3$ is not due to displacement of the central Ti ion. Preliminary studies show that many of the properties of $BaTiO_3$ may be accounted for on the basis of a shift of electronic wave functions. Consider in first approximation each octahedron as possessing independent internal electronic states. If two states of opposite parity lie close together in energy, a large polarizability results. This leads to a spontaneous polarization in the usual Langevin-Weiss manner if we assume an effective internal field $E+\beta P$, and determine the Lorentz factor β by comparison with the experimental dielectric constant and polarization. By properly choosing the level scheme the rste at which polarization sets in below the Curie point can be made equal to the observed value.

[1] B. Matthias, Phys. Rev. **75**, 1771 (1949).
[2] Danielson and Rundle, Phys. Rev. **75**, 1630 (1949); Kay, Wellard, and Vousden, Nature **163**, 636 (1949).

J3. Susceptibility Measurements Using the Moment Balance. J. A. OSBORN, *Naval Research Laboratory.*—A new type of null-reading balance has been designed for that type of susceptibility measurement using a specimen in a non-uniform magnetic field H. Instead of measuring the force on the specimen, as with the Faraday method, an equal and opposite vertical force is applied by a current-bearing coil wound on the capsule containing the specimen. The coil axis is in the applied field direction. The balance is thus returned to its null position. The average field applied to the sample is determined by reversing the magnet field and using the moment coil as a search coil. The coil moment M for a null balance position (known from the turns-area of the moment coil and its current) is determined with the sample in the coil M_i and out of the coil M_0. The total susceptibility χ of the sample is then given by: $\chi=(M_i-M_0)/H$. Advantages and sources of error of this balance will be discussed together with the results of initial measurements on specimens of known susceptibility.

J4. Properties of Single Crystals of Nickel Ferrite. J. K. GALT, B. T. MATTHIAS, AND J. P. REMEIKA, *Bell Telephone Laboratories.*—Single crystals of $NiFe_2O_4$ have been grown in a flux of borax by slow cooling from 1330°C. The amount of borax required is critical, and the oxides apparently dissolve in it, to be precipitated out later in the form of crystals as the charge cools and the borax sublimates. Measurements of dielectric constant and initial permeability have been made. The dielectric constant at liquid air temperature is approximately 20. High conductivity made satisfactory measurements above this temperature impossible. Initial permeability is approximately 100 at room temperature and 15 at liquid air temperature. Saturation magnetization is about 260 c.g.s. units. Data on magnetic anisotropy will be presented.

J5. Ferromagnetic Resonance in Single Crystals of Nickel Ferrite. W. A. YAGER, J. K. GALT, F. R. MERRITT, E. A. WOOD, AND B. T. MATTHIAS, *Bell Telephone Laboratories.*—Ferromagnetic resonance absorption has been observed in spherical samples of single crystals of nickel ferrite. The observations were made at a frequency of about 24,000 mc/sec. The anisotropy constant has been determined from the variation of resonance field as a function of crystallographic orientation using the equations first developed by Kittel.[1] The easy direction is found to be [111], as in magnetite,[2] and the anisotropy constant is $K_1=-6.0\times10^4$ ergs/cc. The g value after correction for anisotropy effects is 2.19. We have found that, if the spheres are as large as 0.039″ diameter, structure occurs in the absorption line which we believe is due to a cavity type electromagnetic resonance in the sphere. This effect can produce an appreciable shift in the field for which maximum absorption occurs. In spheres of about 0.015″ diameter only a single narrow line occurs, however. The width of this line is between 70 and 85 oersteds at all crystallographic orientations. Data on line width as a function of the position of the crystal in the r.f. field has also been obtained.

[1] C. Kittel, Phys. Rev. **73**, 155 (1948).
[2] L. R. Bickford, Jr., Tech. Rpt. XXIII, Laboratory for Insulation Research, M.I.T. (October, 1949).

J6. Theory of Magnetic Dispersion in Ferrites. C. KITTEL, *Bell Telephone Laboratories.*—The a.c. magnetic susceptibility of ferromagnetic ferrites of high electrical resistivity will be composed of two parts: $\chi=\chi_{rot}+\chi_{disp.}$, where χ_{rot} is caused by domain rotation and $\chi_{disp.}$ by domain boundary displacement. The rotational susceptibility has a frequency dependence characterized by spin resonance in the anisotropy field near the frequency $\omega\approx g(e/2mc)(2K/I_s)$, with relaxation frequency Λ. The susceptibility caused by boundary displacement has a relaxation frequency dependence:

$$\chi_{disp.}=\chi_{disp.}{}^0/[1+j2\pi\chi_{disp.}{}^0\omega/nGB_s],$$

where n is the average number of boundaries intercepted by a line of unit length; G is the constant in the boundary velocity equation $v=GH$ and is shown by Landau and Lifshitz[1] to be given by $G=\gamma^2I_s(A/K)^{\frac{1}{2}}/\Lambda$, with magneto-mechanical ratio γ, wall thickness parameter $(A/K)^{\frac{1}{2}}$, and relaxation frequency Λ as above. The interpretation suggested here is in qualitative accord with measurements[2] on magnesium ferrite.

[1] L. Landau and E. Lifshitz, Physik. Zeits. Sowjetunion **8**, 153 (1935).
[2] Welch, Nicks, Fairweather, and Roberts, Phys. Rev. **77**, 403 (1950).

J7. Thin Ferromagnetic Films.* MARTIN J. KLEIN AND ROBERT S. SMITH, *Case Institute of Technology.*—A theoretical study of the magnetization of thin ferromagnetic films has been made using the method of spin waves. The magnetization is known to be of the form A minus B where A is a constant (the magnetization with spins parallel) and B is a sum over all spin wave vectors which gives the effects of out of line spins. We have evaluated the magnetization by replacing the sum B by an integral over λ_x and λ_y (corresponding to spin waves in the plane of the film), and summing explicitly on λ_z (corresponding to waves perpendicular to the plane). When the film is sufficiently thick the latter sum can be replaced by an integral and the film behaves as a three-dimensional crystal, showing spontaneous magnetization which obeys the Bloch $T^{\frac{3}{2}}$ law. When the film is too thin for this replacement, essentially two-dimensional behavior is obtained: B becomes of the order of A indicating no spontaneous magnetization. The thickness at which the transition in behavior occurs depends on the film area and the temperature in a manner which will be discussed.

* Research supported in part by ONR.

J8. Mechanism of Remagnetization in an Initially Saturated Ferromagnet.* H. EKSTEIN AND T. GILBERT, *Armour Research Foundation.*—The mechanism by which a perfect ferromagnetic crystal, magnetized to saturation by an external field, changes its magnetization when the field is reversed has been theoretically investigated, using a method which avoids the difficulty of taking the interaction between the ferroelectrons and the rest of the crystal (conduction electrons, lattice vibrations, etc.) explicitly into account. Reasoning from the results of the Sixtus-Tonks experiments, one can justify the assumption that remagnetization only occurs after the formation of a small nucleus of reversed magnetization. The time required for a nucleus to form after the field is reversed is found to be $t_n=t_{d/6P}$, where t_d is the decay time of a nucleus before the field is reversed and P is the probability of a nucleus occurring before the field is reversed. P is found to be given by $\log P=-1.39n$, where $n\approx10^7$ is the minimum number of spins in a critical nucleus from which remagnetization can

proceed. Since $t_d \approx 10^{-8}$ sec., t_n is extremely large, and it appears that observed remagnetization is probably due to crystal irregularities, non-magnetic inclusions, or inhomogeneous demagnetization fields existing near sharp irregularities at the crystal boundary.

* Supported by ONR.

J9. Effect of Tension on Magnetic Properties in Iron-Cobalt. H. H. PLOTKIN AND J. E. GOLDMAN, *Westinghouse Research Laboratories.*—The influence of tension on the magnetic properties of iron-cobalt of various cobalt compositions has been investigated. Samples of Hiperco 35 and Hiperco 50 (iron-cobalt alloys containing 35 percent cobalt and 50 percent cobalt respectively with small chromium additions)[1] in the form of strips 28×3×.062 cm supplied by J. K. Stanley of this laboratory were measured on a Carr permeammeter.[2] Tensions up to 2000 lb./sq. in. were applied and the complete magnetization curve measured at each value of the tension. For the 35 percent alloy, the permeability increased at all inductions. This is thermodynamically consistent with the known positive slope of the magnetostriction curve of the alloy. In the 50 percent alloy, the permeability is decreased by tension at low inductions but increased at higher inductions. Measurements were extended to a 65 percent cobalt alloy. In the latter case the effect of tension is to increase the permeability at all inductions. An x-ray investigation of the crystal orientation in the 50 percent alloy shows two definite preferred orientations. An explanation of the effect of tension in such a non-random alloy based on the effective demagnetizing force normal to the plane of the sample will be given.

[1] J. K. Stanley, Trans. A.S.M. (1949).
[2] W. J. Carr, Technical Publication No. 85, American Society for Testing Materials (1949).

J10. Magnetostriction in Magnetic Alloys with Preferred Crystal Orientation. J. E. GOLDMAN, *Westinghouse Research Laboratories.*—In grain oriented iron-silicon alloys, the magnetostriction as measured on strip samples is negative at values of induction up to approximately $B_s/\sqrt{2}$. The magnetostriction as a function of induction for alloys of Fe—Co with pronounced grain orientation has also been investigated on samples of similar shape. The results for the 50 percent alloy show a similar negative region although smaller in magnitude. The single crystal magnetostriction constant λ_{100} in the case of Fe—Si is known to be positive. Moreover, the magnetostriction curve for an alloy of 65 percent cobalt-iron shows a positive slope at all inductions suggesting that the magnetostriction constants are likewise positive in the case of Fe—Co where no single crystal data are available. It is suggested that the negative magnetostriction in both cases is due to the large demagnetizing field normal to the plane of the sheet. If the magnetically preferred crystal direction is out of the plane of the sheet, the demagnetizing field causes some of the domains to be magnetized in directions of easy magnetization other than those nearest the field. This can be shown to give rise to a negative magnetostriction even in materials where the magnetostriction constants are positive.

J11. Quantitative Field Mapping by the Electron Optical Shadow Method. J. AROL SIMPSON, *National Bureau of Standards.*—The method described is applicable to electric or magnetic fields of from 1 to 100 microns in extent. It requires only that the field in question have a plane such that an electron ray initially in the plane remain in the plane. Such a plane will be referred to as an "equatorial plane." The data required is a series of shadowgraphs of the field, taken, as previously described,[1] as the field is rotated about an axis perpendicular to the equatorial plane. Measurements made on these shadowgraphs can be reduced by a simple formula involving the constants of the observing instruments to a plot of angular deflection as a function of beam incidence angle and distance from optical axis. A numerical integration method is then applied to obtain the field. The accuracy of the method is discussed as well as the possibility of extension to fields where no "equatorial plane" as defined, exists.

[1] L. Marton and S. H. Lachenbruch, J. App. Phys. 20, 1171 (1949).

J12. Fringe Field Observations of Domains. L. MARTON, J. A. SIMPSON, AND A. VAN BRONKHORST, *National Bureau of Standards.*—The change of the shadow patterns produced by the fringe fields of ferromagnetic domains of a cobalt single crystal are investigated as the crystal is rotated about one edge as an axis. The domains are oriented at approximately right angles to the axis. The shadow patterns show an axis of symmetry which is maintained throughout the rotation, showing an "equatorial plane" through this axis of symmetry. As a result, the actual field strength could be calculated in this plane. Numerical values will be communicated. The investigation of the fringe fields of ferroelectric domains has been continued. It was found that with the reduction of the observing beam intensity, the shadow patterns due to accumulated charge disappeared but small portions of the pattern remained at places where light optical observations indicated the presence of domain boundaries. These domain fields are so weak as to be completely masked by the field of accumulated charge.

J13. A Theorem on the Focusing of Electron Beams in Magnetic Fields of Certain "Mirror" Symmetry, with Two Corollaries, One on the Fringe Effect. P. A. STURROCK, *National Bureau of Standards* (Introduced by L. Marton).—Magnetic fields whose scalar potential has a plane of antisymmetry are considered. The theorem establishes ray equations in a form which displays the focusing properties of a beam traveling near to the plane. The first corollary states the condition that a proposed beam path and proposed focusing conditions should be physically realizable. The second corollary shows that the fringe effects of fields which have sharply defined boundaries may be characterized by a pair of focal lengths for which simple formulas are given.

Invited Paper

J14. Fundamental Processes of Magnetization Shown by Movies. W. SHOCKLEY, *Bell Telephone Laboratories.*

FRIDAY MORNING AT 10:00

National Bureau of Standards, East Building Lecture Room

(A. VON HIPPEL presiding)

Semi-Conductors; Photoelectric Phenomena in Crystals

K1. On the Theory of Noise in Semiconductors. R. L. PETRITZ AND A. J. F. SIEGERT, *Northwestern University.*—The contribution to the noise in semiconductors made by fluctuations in the number of conduction electrons has been calculated by Davydov and Gurevich,[1] Gisolf,[2] and by H. Snyder (unpublished) under the assumption that the probability of

losing a conduction electron by trapping is independent of the number of conduction electrons present. This is not the general case since the trapping probability is proportional to the number of unoccupied localized states and can thus depend on the number of conduction electrons. For the standard model of a semiconductor, where the number of empty localized states equals the number of conduction electrons, we obtain in the low temperature case the power spectrum

$$\frac{1}{2}\frac{euF^2}{R}\left\{\frac{\tau}{1+(\omega\tau/2)^2}+\frac{\tau/2}{1+(\omega\tau/4)^2}\right\}d\nu$$

(Gisolf's notation). We have also computed the general case of which the above and the corresponding term in Davydov's result are the limiting cases.

[1] B. Davydov and B. Gurevich, J. Phys. U.R.S.S. **7**, No. 3, 138 (1943).
[2] J. H. Gisolf, Physica **15**, 8–9, 825 (1949).

K2. Perturbed Periodic Wave Equation in Three Dimensions. PAULA FEUER AND HUBERT M. JAMES, *Purdue University.*—The three-dimensional Schrödinger equation with periodic potential modified by a slowly varying perturbation $V(\mathbf{r})$ has been discussed by Peckar and Slater. Slater[1] expresses solutions as sums of localized orthogonal functions with coefficients obtained by solving a wave equation wherein the potential energy term is a constant plus $V(\mathbf{r})$ and the Laplacian of the Schrödinger equation is replaced by a differential operator of high order, which is effectively the Laplacian when applied to solutions with energies sufficiently near a band edge. In this case Slater's approach can lead also to Peckar's solution. For other energies, Slater's high order differential equation is not easily discussed. A modification of Slater's approach shows that, for cubic lattices and energies not too far from a band edge, Slater's equation can be replaced by an ordinary Schrödinger equation involving an effective potential derived from $V(\mathbf{r})$. This equation corresponds to the effective wave equation found by James[2] in the one-dimensional case, or to a wave equation in which the potential energy is exactly $V(\mathbf{r})$, but the effective mass varies appropriately with $E-V(\mathbf{r})$.

[1] J. C. Slater, Phys. Rev. **76**, 1592 (1949).
[2] H. M. James, Phys. Rev. **76**, 1611 (1949), Eqs. (4.58), (4.59).

K3. Potential Fluctuations in Homogeneous Semiconductors.* HUBERT M. JAMES AND GUY W. LEHMAN, *Purdue University.*—Even in homogeneous semiconductors the random distribution of impurities produces potential fluctuations that may affect conductivity. A theory of these fluctuations has been developed, for impurities with zero or finite activation energies. Their importance is greater the higher the impurity density, the lower the activation energy, and the lower the temperature. They are particularly great in semiconductors with very nearly equal densities N_+ of p-type and N_- of n-type impurities. In Ge, with $N_+=N_-=10^{16}$ impurities/cc, the fluctuations at room temperature are of the order of kT, with range of the order of 10^{-4} cm; a five percent difference in N_+ and N_- reduces their magnitude to half this, and their range to one-fourth. With impurities of a single type, the fluctuations at room temperature range from 0.015 ev for $N=10^{18}$ to 0.0015 ev for $N=10^{14}$, for all activation energies up to 0.1 ev. At lower temperatures the activation energy becomes an important factor. The fluctuations eventually decrease much faster than kT if there is an activation energy, but remain almost constant if the activation energy is zero, becoming important at low temperatures for all N.

* This and the preceding paper were supported in part by a Signal Corps contract.

K4. Electrical Properties of Semiconductors with Macroscopic Discontinuities. J. C. M. BRENTANO AND D. H. DAVIS, *Northwestern University.*—We found that the d.c. conductivity of certain semiconducting materials (Al_2O_3, ZnO, BaO, SnO_2 not CuO, Cu_2O) possessing internal boundaries is time dependent: with a constant external e.m.f. the current decreases with time. This decrease is not exponential but follows approximately the relation $i=A-B\ln t$. After passing the current a reverse current is observed on closed circuit, which also falls off with time. The initial value of this reverse current is larger after the primary current was flowing for a shorter time, it is smaller after the primary current was flowing for a longer time. The d.c. current for small applied potentials ($eV<kT$) does not obey Ohm's law. The a.c. conductivity obeys Ohm's law; it is frequency dependent even for low frequencies. The observed phenomena cannot be interpreted on the ground of simple condenser or electrolytic action at the boundaries. A model accounting for them assumes two types of carriers with different signs and mobilities. The displacement of carriers of high mobility gives origin to space charges at the boundaries which reduce the current. The displacement of carriers of opposite polarity and small mobility establishes dipole layers which partly trap and neutralize the carriers of the first type.

K5. The Transition from Insulating to Metallic Behavior in Semiconducting Silicon. G. W. CASTELLAN* AND F. SEITZ, *University of Illinois.*—Pearson and Bardeen have found that the ionization energy of carriers in pure silicon to which phosphorus or boron are added decreases with increasing concentration and becomes zero for concentrations in the vicinity of $5\cdot10^{18}$ per cc. This result is obtained from a range of temperature in which the fraction of donator or acceptor levels that are ionized lies between 1 and about 0.1, the most accurate values of the ionization energy being derived for the latter end of the range. Pearson and Bardeen have suggested that the decrease in ionization energy arises from the attractive Coulomb interaction between the free carriers and the ionized impurity atoms. It is pointed out that if this is the important interaction its contribution should depend primarily upon the density of carriers and not upon the density of impurity atoms and should become very small when the density of carriers is small. In fact the agreement found by Pearson and Bardeen on the basis of their assumption diminishes when as few as a tenth of the centers are ionized. Moreover, the experimental evidence suggests that the ionization energy actually depends upon the total density of impurity atoms and not upon the density of free carriers.

* AEC postdoctoral fellow.

K6. Theory of Infra-Red Absorption in Silicon and Germanium. J. BARDEEN, *Bell Telephone Laboratories.*—Mobile carriers and those weakly bound to donors and acceptors contribute to the absorption in germanium and silicon in the infra-red.[1,2] The magnitude of this absorption is much larger than that given by the semiclassical Drude-Zener theory which expresses the absorption in terms of the relaxation time, τ_0, associated with the low frequency conductivity. In an attempt to resolve this discrepancy, we have made a quantum-theoretical calculation based on second-order transitions in which a carrier absorbs a photon and emits or absorbs a phonon. Direct absorption by mobile carriers is forbidden by selection rules and is small for bound carriers. The formula obtained is similar to the classical except that τ_0 is replaced by an average value corresponding to the excited electron. If only the acoustical modes are considered, the theory gives an increase in absorption which is insufficient to account for the discrepancy. It is suggested that the absorption results mainly from interaction of the carriers with higher vibrational modes which can be excited if the incident photons have sufficient energy. Such absorption is relatively temperature independent.

[1] M. Becker and H. Y. Fan, Phys. Rev. **76**, 1531 (1949).
[2] H. B. Briggs, Phys. Rev. **77**, 727 (1950).

K7. Metallographic Study of Germanium Point Contact Rectifiers. M. H. DAWSON AND B. H. ALEXANDER, *Sylvania Electric Products, Inc.*—Germanium point contact rectifiers were prepared and mounted in methyl methacrolate. These units were ground down parallel and perpendicular to the tungsten whisker. For those units ground in a direction perpendicular to the whisker, the peak inverse voltage and the forward current started to decrease when the thickness of the Ge became less than 8×10^{-3} in. An explanation for this phenomena is discussed. Those units ground down to reveal the nature of the whisker-germanium contact exhibited a characteristic pit immediately below the whisker contact. Little change was observed in the reverse current before and after pitting, but the forward current dropped markedly. These phenomena indicate that the forward current flows throughout the contact area whereas the reverse current flows only at the periphery of the contact. Upon pulsing the rectifier and watching the contact under high magnification, the germanium was observed to melt for a region within 2×10^{-3} cm of the contact.

K8. Photo-conductivity of Trapped Electrons in the Alkali Halides. J. J. OBERLY AND E. BURSTEIN, *Naval Research Laboratory.*—Data obtained at room temperature show a considerable difference in the relative response of the various color center bands—*F*, *R*, *M*, *N*[1]—and also in the relative response of the *F*-band itself following various treatments of the crystal. All of these bands were known to be bleached by monochromatic light and thus perhaps photo-conductive. In a KCl crystal colored by a short exposure to x-rays, only the *F*-band was present and it was quite photo-conductive as reported by others. On the other hand, in an additively colored KCl crystal which had all of the absorption bands present in strength, the *F*-band was much less photo-conductive; the *R*- and *N*-bands showed considerable response, but the *M*-band comparatively little. It was noted that weak *N*-band response was obtained when no appreciable *N* absorption band was present. This behavior of the *F*-band, as well as other of its properties, would appear to indicate that it is a superposition of bands due to different types of centers. Other mechanisms which could account for this behavior will be discussed. Measurements to be made at low and high temperatures should provide more conclusive evidence.

[1] E. Burstein and J. J. Oberly, Phys. Rev. **76**, 1254 (1949).

K9. The Nature and Properties of Trapped Holes in the Alkali Halides. E. BURSTEIN AND J. J. OBERLY, *Naval Research Laboratory.*—The trapping of positive holes by positive ion vacancies in the alkali halides should be closely analogous to the trapping of electrons by negative ion vacancies. Color centers associated with holes trapped at positive ion vacancies and aggregates of positive ion vacancies may be expected under appropriate conditions which are analogous to the *F*, *F'*, *R*, *M*, and *N* centers associated with trapped electrons. Further, the color centers due to trapped holes should exhibit optical properties similar to those of trapped electrons, and a number of these centers should be photo-conductive, yielding free holes either by direct optical excitation (as for *F'* centers) or indirectly by a combination of optical and thermal excitation (as for *F* centers). The stability of the various trapped hole centers at any given temperature will in general differ markedly from that of trapped electron centers as a result of differences in the thermal diffusion and rate of aggregation of trapped holes and electrons which are associated with differences in the thermal diffusion of positive and negative ion vacancies. Recent measurements on trapped hole color centers will be discussed in the light of these considerations.

K10. Constant Quantum Efficiency of Some Luminescent Materials in the Vacuum Ultraviolet. K. WATANABE, F. S. JOHNSON, AND R. TOUSEY, *Naval Research Laboratory.*—The quantum efficiency of fluorescence was found by Harrison and Leighton[1] to be constant from 2400 to 4000A for aesculin and certain oils. We have found constant quantum efficiency for pump oil and a few other materials from 2400 to 900A. A vacuum monochromator and hydrogen discharge tube source were used. The resolution was 16A or less. The energy emerging from the exit slit was known from measurements made by Packer and Lock[2] with a thermocouple. The phosphor studied was coated on the envelope of a photo-multiplier placed in vacuum an inch behind the exit slit, and an area approximately 10 mm^2 was irradiated. This result makes it possible to use a fluorescent material and a photo-cell for making energy measurements instead of a thermocouple, and extends to 900A the region over which heterochromatic photographic photometry can be carried out by Harrison and Leighton's method.[1] Materials were found with adequate response speed and stability and with linear intensity of fluorescence over the intensity range covered. Among other phosphors studied, were counting crystals such as $CaWO_4$, CaF_2, LiF, and anthracene.

[1] G. R. Harrison and P. A. Leighton, Phys. Rev. **38**, 899 (1931).
[2] D. M. Packer and C. Lock, Paper No. 65, Meeting of the Optical Society of America, March 11, 1950.

K11. Some Phenomena in Diamond Gamma-Ray Counters.* E. PEARLSTEIN† AND R. B. SUTTON, *Carnegie Institute of Technology.*—Gamma-ray counting diamonds have been studied with respect to polarization[1] and the effects of heat treatment. It is found that the counting rate decreases and then increases with time, for high field strengths (~10,000 volts/cm); for low field strengths the counting rate monotomically decreases. If a diamond is given a heat treatment of 400°C for ten minutes its counting properties are changed as follows: The counting rate is initially much lower than before heat treatment; while counting it further decreases, then slowly rises to its value before heat treatment. If the diamond is one which before heat treatment could be polarized with no irradiation it cannot become so polarized after treatment. Several hours' exposure to gamma-rays or a few seconds' exposure to ultraviolet light nullifies the heat treatment. To explain this behavior more than one set of impurity levels appears to be required. Data on electron range and mobility, measured with unpolarized samples, will be given.

* This work was supported by the Bureau of Ships and ONR.
† AEC predoctoral fellow.
[1] See R. K. Willardson and G. C. Danielson, Phys. Rev. **77**, 300 (1950) and the references quoted therein.

K12. Scintillation Spectra of Some Organic Crystals. W. S. KOSKI AND C. O. THOMAS, *Johns Hopkins University.*—Using a Hilger quartz spectrograph and Eastman 103-0 plates the scintillation spectra of a series of structurally related organic crystals was measured. The same spectra were obtained for any one crystal, regardless of whether the mode of excitation was due to α-, γ-, or x-rays. The data are as follows.

Crystal	Wave-length of center of band	Width at half-max.
Diphenylethane	3925±50 (weak)	——
	3765 (strong)	400
	3525 (strong)	——
	3395 (weak)	
Stilbene	3975 (strong)	375
Tolane	3775	315
Bistyryl	4585 (strong)	325
	4395 (weak)	

The apparent correlation between structure of the molecules and the intensity and spectra of the scintillations will be discussed.

FRIDAY MORNING AT 10:00

Department of Interior Auditorium

(E. T. BOOTH presiding)

Mostly Pertaining to Neutrons

L1. Nuclear Energy Levels in Lead.* R. K. ADAIR,† C. K. BOCKELMAN, AND R. E. PETERSON, *University of Wisconsin.*—Total cross-section measurements for fast neutrons have been made on Pb^{206}. Values of the cross section were determined by transmission experiments using neutron energy spreads of 5 kev and 3 kev. Resonances were observed, many of which took the form of dips rather than peaks. The average spacing between levels appears to be about 50 kev. Previous investigations of ordinary Pb had disclosed the presence of three resonances which were attributed to levels in Pb^{209}, the compound nucleus formed by the interaction of neutrons with Pb^{208}.[1] These peaks have been reinvestigated with a neutron energy spread of about 3 kev. The height of the peaks so measured, together with the knowledge of the variation of the part of the cross section attributed to Pb^{206}, allows a more reliable determination of the spins and widths of the levels in Pb^{209}.

* Work supported partly by the AEC, partly by the Wisconsin Alumni Research Foundation.
† AEC Predoctoral Fellow.
[1] Barschall, Bockelman, Peterson, and Adair, Phys. Rev. **76**, 1146 (1949).

L2. Nuclear Energy Levels in Sulfur.* R. E. PETERSON, R. K. ADAIR, H. H. BARSCHALL, AND C. K. BOCKELMAN, *University of Wisconsin.*—The total neutron cross section of sulfur has been measured for neutron energies in the range 15 to 750 kev. Neutron energy spreads of from 4 to 9 kev were used in making a survey of the variation of cross section with neutron energy; certain energy regions were later re-investigated with an energy resolution of from 1.5 to 3 kev. Nine maxima in the cross section were observed in the energy interval studied. These are attributed to the effect of energy levels in S^{33} producing resonances in the elastic scattering. Maxima observed at 111, 375, and 700 kev are preceded by minima presumably caused by interference between resonance and potential scattering;[1] s-neutrons should be responsible for these resonances. p-neutrons, yielding compound nuclei of spin $3\hbar/2$, probably cause a resonance observed at 585 kev. The remaining maxima are believed to be due to neutrons of one unit of angular momentum also. Natural widths of the resonances at 111, 375, 585, and 700 kev are estimated to be 18, 12, 1.5, and 12 kev, respectively.

* This work was supported by the Wisconsin Alumni Research Foundation and the AEC.
[1] Adair, Bockelman, and Peterson, Phys. Rev. **76**, 308 (1949).

L3. Neutron Capture-Radiation from Heavy Elements, G. A. BARTHOLOMEW, B. B. KINSEY, AND W. H. WALKER, *Chalk River.*—The spectra of the gamma-radiation produced by slow neutron capture in heavy elements have been measured with the aid of a pair spectrometer. Cu, Zn, Sr, Cd, In, Sn, W, and Au all produce anumber of homogeneous radiation superimposed on a continuous background of unresolved radiations (resolution 2 percent). The Pb spectrum contains two radiations only, which are emitted in direct ground state transitions of Pb^{207} and Pb^{208}. Bi emits radiations corresponding to transitions from the capturing state to low lying excited states in Bi^{210}. These simple spectra may be associated with closed neutron and proton shells. The spectrum of Sn (50 protons), on the other hand, is similar to those of other heavy elements.

L4. Fast Neutron Capture Cross Section of AL^{27} as a Function of Energy.* R. L. HENKEL AND H. H. BARSCHALL, *University of Wisconsin.*—The fast neutron capture cross section of Al^{27} has been measured by observing the 2.4-minute β-activity of Al^{28}. This activity was induced by neutrons of energies between 150 and 700 kev. Radiative capture is the only absorption process in this energy range. Neutrons of variable energy were produced by the $Li^7(p,n)Be^7$ reaction, using the Wisconsin electrostatic generator. Cross sections were determined by comparison with the known thermal capture cross section of aluminum. A BF_3 proportional counter was employed for monitoring the neutron flux during this comparison, making use of the known energy dependence of the disintegration cross section of boron. The aluminum capture cross section in the energy range studied has values between 1 and 6 millibarns and shows resonance levels corresponding reasonably well to those levels found in the total neutron cross section. A quantitative comparison between level energies is made difficult by the complicated level structure and the poor energy resolution (20 to 30 kev) used in this preliminary work.

* Work supported partly by the AEC, partly by the Wisconsin Alumni Research Foundation.

L5. Neutron Capture γ-rays from Mg, Si, P, and K. B. B. KINSEY, G. A. BARTHOLOMEW, AND W. H. WALKER, *Chalk River.*—Pair spectrometer measurements of the γ-radiation resulting from slow neutron capture in Mg^{24} and Mg^{25} have failed to reveal direct transitions from the capturing state to the ground state. Radiations emitted in transitions to excited states are observed. The direct ground state radiations produced by capture in Si^{28} and Si^{29} were found to be very weak. Those produced by capture in K^{39} and K^{41} are much stronger although they are weaker than radiations emitted in transitions to excited states. Two units of angular momentum must be radiated in the ground state transitions following capture in Mg^{24} and K^{39}, one or two units in P^{31} and possibly one unit only in Si^{28}. It will be shown that the intensities of these radiations relative to those producing excited states cannot be explained in terms of selection rules which depend only on changes in nuclear spin and parity.

L6. On the Scattering of Slow Neutrons by Solid Helium. L. GOLDSTEIN AND D. SWEENEY, *Los Alamos Scientific Laboratory.*—The theory of slow neutron scattering by crystals has been applied to solid heavy helium at temperatures less than about 4°K and at neutron kinetic energies larger than about twice the approximate Debye temperature (~35°K) of solid helium. The coherent scattering cross section per atom is found to be small in comparison with the free atom scattering cross section especially at higher neutron energies. This reduction is due to the very large zero-point energy term in the exponent of the exponential temperature factor. As a result the coherent scattering becomes practically temperature independent. The incoherent scattering is a multiphonon excitation process at the neutron energies considered here. The incoherent scattering cross section is also practically temperature independent and tends, at large neutron energies, toward the free atom scattering cross-section value. The theory is being extended to the extreme solid model of liquid helium, the latter being assumed to have also the ideal hexagonal close packed structure which appears to be the most probable structure of the solid.

L7. Neutron Scattering Resonance in Cl^{35} at −73 Ev. C. T. HIBDON AND C. O. MUEHLHAUSE, *Argonne National Laboratory.*—Using a 4π-BF_3 annular neutron scattering chamber and a resonance neutron beam from the Argonne heavy water reactor, the total neutron cross section of chlorine was measured at 120 ev, 345 ev, and 2700 ev by the resonance scattering detection of Co, Mn, and V respectively.[1] By subtracting the $1/v$ absorption term, the scattering cross sections were obtained at these energies. The coherent neutron scattering cross section and the thermal scattering cross section[2] for chlorine were used to evaluate the thermal scattering amplitude, $\lambda\Gamma/2E_0$, as $\simeq 1$. The data is consistent with the following expression for the one-level Breit-Wigner scattering cross section, σ_s, as a function of energy when $E-E_0 \gg \Gamma$:

$$\sigma_s = 1.37 + \frac{600}{E+73} + \frac{24500}{(E+73)^2}, \quad (E>0).$$

The resonance parameters for Cl^{35}, $(i=\frac{3}{2})$, have the following values:

$$J=2, \quad R=0.82\times 10^{-12}\ \text{cm}\ \frac{\Gamma n}{\Gamma} \simeq 0.9.$$

[1] C. T. Hibdon and C. O. Muehlhause, Phys. Rev. **76**, 100 (1949).
[2] E. O. Wollan and C. G. Shull, Phys. Rev. **73**, 830 (1948).

L8. Neutron Scattering Cross Sections of the Noble Gases. S. P. HARRIS, *Argonne National Laboratory.*—Using the annular BF_3 scattering chamber described previously,[1,2] the scattering cross sections of He, Ne, A, Kr, and Xe were measured for sub-cadmium and resonance neutrons. Only Kr and Xe showed cross sections high enough so that it was significant to measure their transmission in these regions by self-indication. A small aluminum cell having 2-mil aluminum windows and filled with the gas to be measured was placed in the center of the annular chamber. This served as detector by scattering neutrons from the beam. A[3], Kr, and Xe all indicated resonances via boron absorption. The greatest resonance effect was in Xe. Its effective scattering cross section (by comparison with graphite) was highest with only cadmium filtering (about 20 barns). Under the same conditions the self-indication transmission cross section was about 500 barns. Xe thus appears to have a resonance with a considerable portion of scattering in the energy region of a few electron volts. The resonance (or resonances) is probably associated with one of the even Z odd N isotopes (Xe^{129} or Xe^{131}).

[1] Harris, Langsdorf, and Seidl, Phys. Rev. **72**, 866 (1947).
[2] C. T. Hibdon and C. O. Muehlhause, Phys. Rev. **76**, 100 (1949).
[3] E. Melkonian, Phys. Rev. **76**, 1750 (1949).

L9. Capture γ-Ray Multiplicity. C. O. MUEHLHAUSE *Argonne National Laboratory.*—The average number of γ-rays, $\nu\gamma$, per neutron capture was measured for about thirty isotopes. A thermal plus resonance neutron beam from the Argonne Heavy Water Reactor was made to pass through various thin neutron absorbing foils. Two anthracene scintillation counters in coincidence straddled the beam and foils. The ratio of coincidence to single counting rate, c/s, was recorded for each absorber. c/s is proportional to $\nu\gamma - 1$, and calibration was effected with the γ-rays from Co^{60} and Na^{24}. In the cases of Mn^{55}, As^{75}, and Au^{197} $\nu\gamma$ was measured for both thermal and resonance neutrons, and found to be independent of neutron energy. Gamma-ray angular correlations were also investigated, but no significant effects were found. Correlations of $\nu\gamma$ with atomic weight, level density, and nuclear type (odd and evenness of protons and neutrons) will be presented.

L10. Angular Distribution of Neutrons from 15-Mev Deuterons on Thick Cyclotron Targets.* C.E. FALK, *Carnegie Institute of Technology.*—It has been reported at an earlier date that the angular distributions of neutrons resulting from the bombardment of thick targets by deuterons of about 15 Mev was very sharply peaked in the forward direction. With the help of a counter telescope, consisting of four proportional counters with variable aluminum absorbers in front of the first and fourth counter, anti-coincidence analyzer, and threshold detectors, the study of the above phenomena has been extended. It has been found that the distributions consist sometimes of a single peak in the direction of the deuteron beam and sometimes of double peaks symmetric about the direction of the deuteron beam. The distribution can possibly be explained by stripping, the double peaks being caused by the Coulomb interaction. Neutron spectra have been taken at several parts of the angular distributions. The interpretation of the spectra with respect to stripping theory will be discussed.

* This work was carried out with the assistance of ONR.

L11. The Inelastic Scattering of High Energy Neutrons by Deuterons and the Neutron-Neutron Interaction. GEOFFREY F. CHEW, *University of California, Berkeley.*—Because elastic scattering represents a considerable fraction of the total *n-d* cross section even at high energy,[1,2] it is dangerous to assume that the latter is composed additively of *n-p* and *n-n* cross sections. Non-additive effects are less important in inelastic scattering, however, and one may attempt to derive information about the high energy *n-n* cross section from an observation of the disintegration protons. A theoretical approach has been developed to relate *n-d* inelastic scattering to free *n-p* and *n-n* scattering cross sections at the same energy, *without reference* to the nature of nuclear forces. The method depends on the short range of nuclear forces and on the smallness of two-body cross sections compared to the size of the deuteron but is *not* a Born approximation. Analysis of Powell's[2] preliminary data on this basis indicate the 90-Mev *n-n* cross section to be *less* than 15 mb. Since the proton-proton cross section at 350 Mev is ~30 mb,[3] doubt is cast on the equality of *n-n* and *p-p* interactions at high energies. This work was sponsored by the AEC.

[1] G. F. Chew, Phys. Rev. **74**, 809 (1948).
[2] See Abstract by W. Hartsough, M. Hill, W. M. Powell.
[3] Chamberlain and C. Wiegand, Bull. Am. Phys. Soc. **25**, No. 1, H-6 (1950).

L12. Deuterons Bombarded by 90-Mev Neutrons.* WALTER HARTSOUGH, MILTON HILL, AND WILSON M. POWELL, *University of California, Berkeley.*—A deuterium filled Wilson cloud chamber with heavy water vapor in a 21,700-gauss field was bombarded by 90-Mev neutrons produced by 190-Mev deuterons bombarding a half-inch thick beryllium target. The deuterons in the cloud chamber are elastically scattered one-third of the time and show a sharp peak in the forward direction in accord with "pick-up" theory,[1] a valley at 30 degrees, and another peak at 80 degrees. The proton fragments show a broader peak forward reaching half-value at 35 degrees. A few protons go backward, and one might interpret these as the residue of neutron-neutron collisions.[2] They amount to about five percent of the total number of events and may be used to obtain a rough estimate of the total neutron-neutron cross section relative to that of the deuteron.[3] This work was supported by the AEC.

[1] G. F. Chew and M. L. Goldberger, Phys. Rev. **77**, 470 (1950).
[2] See Abstract by G. F. Chew.
[3] Cook, McMillan, Peterson, Sewell, Phys. Rev. **75**, 7 (1949).

FRIDAY MORNING AT 10:00

National Academy

(I. I. RABI presiding)

Theoretical Physics, Largely Nuclear

M1. Scattering of Light by Light. ROBERT KARPLUS AND MAURICE NEUMAN, *Institute for Advanced Study.*—Previous investigations of the interaction of light with an electromagnetic field were beset by difficulties due to the appearance of divergent integrals and non-gauge invariant expressions. The recent improvements in the perturbation techniques of field theory, however, have made the calculation of these effects feasible. Accordingly a convergent, gauge invariant, and closed expression for the non-linear terms in the Lagrangian responsible for this interaction in the lowest non-vanishing order has been obtained. It could serve as a basis for the calculation of the scattering of light by light or by a Coulomb field and of processes like the triple decay of a neutral vector meson into photons. The integrations were carried out for the scattering of light by light and the differential cross section evaluated in the center of gravity system for unpolarized photons. The exceedingly complicated formula, expressible in terms of Spence's transcendents and elementary functions, simplifies greatly in the limits of high and low energies. The cross section at the pair threshold for 90° scattering is $d\sigma = 2.73 \times 10^{-30}(d\Omega/4\pi)$ cm².

M2. Singular Potentials. K. M. CASE.—For a potential which is highly singular at the origin the conventional methods of solving the Schrödinger equation fail. Non-relativistically this occurs for a $1/r^n$ potential with $n \geq 2$. The relativistic wave equations for spin 0, ½, or 1 in a sufficiently strong Coulomb field are similarly "singular." In these cases the differential equations have too many rather than too few solutions quadratically integrable near the origin. This incompleteness in the specification of the Hamiltonian operator may be removed by giving one additional parameter which is most conveniently taken as a phase angle. Then the above problems all yield a complete set of quadratically integrable solutions. Since in the non-relativistic cases the point spectrum always extends to $-\infty$ such potentials are of little physical use except as an approximation in scattering problems. In relativistic problems the situation is different since the discrete spectrum is restricted to the interval between plus and minus mc^2. Solving the Dirac equation with $\alpha Z > 1$ gives two discrete sets of levels. One set approximates the levels for $\alpha Z < 1$ while the others cluster around plus and minus mc^2. The interpretation is that of positrons bound in a repulsive potential. An analysis of the situation indicates that the conjecture that real pairs are produced at $Z = 137$ is probably unfounded.

M3. Non-Linear Spinor Fields. R. FINKELSTEIN AND M. RUDERMANN, *University of California at Los Angeles, and California Institute of Technology.*—We have investigated certain classical theories described by non-linear spinor field equations. In one example both plane wave and localized solutions exist. A rigorous separation of the field equations into angular and radial parts is possible and the resulting radial equations can be integrated accurately. The corresponding particles have positive mass, spin, magnetic moment, and tensor interaction, and may have +, −, or 0 charge.

M4. Velocity Dependent Nuclear Interactions.* R. AVERY, C. H. BLANCHARD, AND R. G. SACHS, *University of Wisconsin.*—Mayer's considerations on the relationship between nuclear shell structure and strong spin-orbit coupling suggest that the velocity dependent interactions listed by Wigner should be investigated. These interactions introduce additions to nuclear magnetic moments over and above the spin and orbital moments. On the assumption that this "interaction moment" should vanish for H^2 and be equal and opposite in the ^2S states of H^3 and He^3, possible interactions are

$$J(|\mathbf{r}_j-\mathbf{r}_k|)[(\mathbf{r}_j-\mathbf{r}_k)\times(\mathbf{p}_j-\mathbf{p}_k)]\cdot\begin{cases}(\boldsymbol{\sigma}_j-\boldsymbol{\sigma}_k)(\tau_{j3}-\tau_{k3})\\ [\boldsymbol{\sigma}_j\times\boldsymbol{\sigma}_k][\boldsymbol{\tau}_j\times\boldsymbol{\tau}_k]_3.\end{cases}$$

The interaction moment due to either of these interactions, introduced with a strength comparable to that of the usual interactions, can account for the observed anomalies in the H^3 and He^3 moments. Both interactions vanish between like particles; they differ only by a space exchange factor. Neither would affect the low energy properties of the two-body system. They can, however, be expected to modify high energy NP (but not PP) scattering.

* This work was supported by the AEC.

M5. Non-Perturbation Calculation of the Nucleon-Meson Coupling Constant. S. D. DRELL, *University of Illinois.*—Equations of motion are derived from a Lagrangian describing the interaction between a Dirac spinor field (nucleon) and a Yukawa field (meson). The fields are not quantized. Elimination of the meson field variables yields a non-linear equation for the nucleon field. Because of this non-linearity there exist lumps in the field which can be interpreted as particles.[1] Quantized values for the nucleon-meson coupling constant, $g^2/4\pi\hbar c$, result when the nucleon field is normalized to unit charge. We introduce four component spinor trial wave functions into an integral which is constructed so as to assume a stationary value when the nucleon field amplitudes satisfy the non-linear equation. A variation with respect to parameters in the wave functions is performed. A stationary state of a localized nucleon is found to exist for scalar mesons, scalar coupling. A lower bound of $g^2/4\pi\hbar c \approx 0.6$ to 0.8 is obtained. Results are unchanged for treatment of nucleons as Yukawa particles. No stationary states are found for a localized nucleon under the influence of a pseudoscalar meson field with pseudoscalar coupling.

[1] R. J. Finkelstein, Phys. Rev. **75**, 1079 (1949).

M6. Absorption of π^--Mesons by Protons. R. E. MARSHAK, *University of Rochester,* AND A. S. WHITMAN, *Princeton University.*—Panofsky[1] has observed high energy gamma-rays resulting from the absorption of slow π^--mesons by protons. His data can be interpreted most simply in terms of a competition between γ and π^0 (neutral meson) emission.[2] The γ-emission leads to a line at 130 Mev whereas the π^0-emission gives a square pulse of γ's centered at about half this energy. The width w of the pulse yields a sensitive determination of the mass μ_0 of π^0 while the ratio h of the heights of the pulse and the line fixes the π^0-nucleon coupling constant g. Using Panofsky's admittedly crude values $w = 35 \pm 15$ Mev, $h = 10 \pm 2$, we find $\mu_0 c^2 = 135^{+2}_{-5}$ Mev, $g^2/\hbar c = 0.55^{+0.3}_{-0.1}$ (pseudoscalar theory for both π^- and π^0) or $g^2/\hbar c = 0.07^{+0.04}_{-0.01}$ (scalar theory[2] for both π^- and π^0). Opposite parities for π^- and π^0 (pseudoscalar for π^-, scalar for π^0 or conversely) can be excluded be-

cause the coupling constant would become unreasonably large ($g^2/\hbar c$ would be multiplied by a factor $(Mc^2/w)^2 \approx 500$ where M is the nucleon mass). Conclusions can be drawn about the relative sign of coupling of π^0 with neutron and proton.

[1] W. K. H. Panofsky, post-deadline paper at New York meeting (1950).
[2] R. E. Marshak and A. S. Wightman, Phys. Rev. **76**, 114 (1949).

M7. The Absorption of π^--Mesons by Deuterons. STEPHEN TAMOR,* *University of Rochester.*—The non-radiative absorption of pseudoscalar π^--mesons by deuterons has been calculated.[1] There is a qualitative difference between scalar and pseudoscalar mesons. If absorption of the π^--meson from the K shell is considered, the Pauli principle applied to the final two neutron system forbids non-radiative absorption of scalar mesons. Instead, the absorption is accompanied by a continuous γ-ray spectrum with a peak at 135 Mev and a width of 10 Mev. For pseudoscalar mesons, the radiative absorption is slower by a factor of 10^3 compared to the non-radiative absorption. The absorption of π^--mesons accompanied by the emission of neutral mesons will also be discussed.[2]

* AEC Fellow.
[1] C. Marty and J. Prentki, J. de phys. et rad. **10**, 156 (1949).
[2] See abstract M6.

M8. Scattering of Mesons by Nucleons. MURRAY PESHKIN.* *Cornell University.*—The scattering of scalar and pseudoscalar mesons by nucleons has been calculated to the lowest order in which it appears, using the field theoretic methods of Feynman. Charged and mixed theories have been considered, and the computations have been carried out exactly for all energies. For a given nucleon, two different Feynman diagrams are needed, one in the case of a positive meson, and the other for a negative meson.[1] Only one enters in each problem because the order (along the nucleon line) of absorption and emission depends upon the charges. These lead to nearly equal cross sections, the difference being negligible whenever the recoil energy of the nucleon can be ignored. The cross section for a charged meson to lose its charge to the nucleon in the scattering process receives contributions from both diagrams. In the pseudoscalar theory, this cross section is $a[(\sigma_1)^{\frac{1}{2}} - (\sigma_2)^{\frac{1}{2}}]^2$, where a depends upon the mixture, while in the scalar theory the interference is not destructive. This difference, if higher order terms bear it out, may provide an experimental method for distinguishing between the two theories.

* AEC predoctoral fellow.
[1] R. P. Feynman, Phys. Rev. **76**, 775 (1949), Fig. 5.

M9. The Scattering of Gamma-Rays by Protons.* R. G. SACHS, *University of Wisconsin*, AND L. L. FOLDY, *Case Institute of Technology.*—The cross section for the scattering of gamma-rays with energy near the threshold for meson production has been calculated on the basis of the symmetrical scalar and pseudoscalar meson theories. The calculation was carried out in the non-relativistic, weak coupling approximation, neglecting nucleon recoil effects. No divergence difficulties were encountered. In the scalar theory, the total cross section is somewhat less than the Thompson cross section (σ_0) as a consequence of interference between the scattering by the nucleon and that by the meson cloud. In pseudoscalar theory the total cross section varies strongly with energy as a result of interference effects and attains a value as high as $4\sigma_0$. The angular distribution in the scalar theory is very similar to that given by the Klein-Nishina formula: $\frac{1}{2}(1+\cos^2\theta)$. The pseudoscalar theory gives a quite asymmetric distribution, the form of asymmetry depending strongly on energy. All results are rather sensitive to the choice of coupling constant. The results may be taken as a strong indication that observation of the process could yield, in a sensitive way, information concerning the structure of the proton.

* Supported in part by the AEC.

M10. Electric Processes Involved in Deuteron Reactions.* M. L. GOLDBERGER, *M.I.T.*—Recent experiments by Boyer and his collaborators[1] on nuclear reactions produced by 14 Mev deuterons have indicated that some of the phenomena involved in deuteron reactions may be attributed to electric processes. We have studied the elastic and inelastic scattering together with the electric stripping process. In connection with the latter, we have taken into account accurately the influence of the Coulomb field on the stripped protons. This feature has been neglected in previous investigations.[2] The effect of the smeared out charge distribution of the deuteron on the elastic and inelastic scattering processes will be discussed and will be related to the tendency of the deuteron to stick together after having undergone a given momentum transfer.

* This work was supported by the joint program of the ONR and AEC.
[1] To be reported at this meeting.
[2] J. R. Oppenheimer, Phys. Rev. **47**, 845 (1935), S. M. Dancoff, Phys. Rev. **72**, 1017 (1947).

M11. Effect of Tensor Forces on the Level Structure of Li^6 and Li^7. A. M. FEINGOLD AND E. P. WIGNER, *Princeton University.*—An investigation of the effect of tensor forces on the level structure of Li^6 and Li^7 has been made by treating the tensor force as a perturbation on the low lying level structure given by central forces. As far as the normal states are concerned, the effect of the tensor forces manifests itself only in the second order of the perturbation calculation. First only such excited states have been considered in which the s^4 configuration of the He^4 core remained unaffected. This gave consistently unsatisfactory results: the large energy difference between He^6 and Li^6 could not be accounted for, and the $J=\frac{1}{2}$ state of Li^7 fell below the $J=\frac{3}{2}$ state. These results were independent of the exchange character of the tensor forces. Taking into account the possibility of the excitation of the He^4 core gave, however, a splitting between the $P_{3/2}$ and $P_{\frac{1}{2}}$ states of a single p particle.

M12. The Effect of the Nuclear Charge and of Interference on Calculated $\beta-\gamma$ Correlations. M. FUCHS AND E. S. LENNOX, *University of Michigan.*—The many negative experimental attempts to find $\beta-\gamma$-correlations have led us to consider two effects which one might think tend to modify or destroy the correlation and which were not calculated by Falkoff:* (1) The influence of the nuclear charge. This is essentially an internal scattering which might make the angular distribution of the outgoing β-particle more isotropic. (2) Interference between matrix elements for a given β-interaction and degree of forbiddenness. We have calculated the first effect using both non-relativistic and relativistic coulomb wave functions for the emitted β-particle. The indications are that the effect of the nuclear charge is different for different β-interactions but is generally quite small. Interference was calculated for the upper end of the β-spectrum and strongly affects the correlation in magnitude and sign. It takes, however, very special choices of relative amplitude and phase for the matrix elements to give zero correlation. Numerical results will be given for both these effects.

* D. L. Falkoff, dissertation, University of Michigan (1948).

FRIDAY MORNING AT 10:00

Department of Commerce Auditorium

(C. C. LAURITSEN presiding)

Papers Not Classed Elsewhere

N1. A High Constant Speed Rotating Mirror.* E. C. SMITH AND J. W. BEAMS, *University of Virginia.*—A magnetic stainless steel rotor with symmetrically spaced optically flat polished surfaces is freely suspended in vacuum by an improved magnetic suspension.[1] The mirror is spun by a rotating magnetic field, the frequency of which is controlled by a piezoelectric crystal. It accelerates like a high resistance armature of an induction motor and because of the low frictional torque, pulls into synchronism with the rotating field and spins without hunting. Consequently, its rotational speed is as constant as the frequency of the crystal. The mirror speed is limited only by its mechanical strength and is set by the frequency of the crystal (10^5 cycles/sec.) used or one of its submultiples. Lateral motion of the rotor is damped by freely suspending the core of the supporting solenoid as a pendulum in an oil dash pot. The period of the pendulum is made equal to the lateral period of the rotor. The mirror has no observable horizontal or lateral motion and is very stable. It was developed for use in the study of short time phenomena and for possible use in velocity of light measurements.

* This work was supported by the Navy Bureau of Ordnance.
[1] Beams, Young, and Moore, J. App. Phys. **17**, 886 (1946).

N2. The Velocity of Electromagnetic Waves and the Dielectric Constant of Dry Air.* J. V. HUGHES, *Queen's Univeristy.*—Essen[1] and Aslaskan[2] have pointed out a discrepancy between the accepted value of the velocity of light, 299,775 km/sec., and the mean of six recent values for the velocity of radio waves, 299,790. Five of the radio results were determined in air and corrected to vacuum using a dielectric constant of air obtained at 1 Mc/sec. The following table shows values for the dielectric constant of dry air at N.T.P., which would need to be 1.00048 to obtain agreement between velocities. The author's

Observer	Measurement freq.	k for dry air
Meggers and Peters	Visible light	1.000575
Englund, Crawford, and Mumford	1 Mc/sec.	1.000590
C. M. Crain	9000 Mc/sec.	1.000572
Author and Lavrench	3000 Mc/sec.	1.00060

results have rather a wide spread, so that the difference from Englund's result is probably not significant, but clearly a value of 1.00048 is impossible. The discrepancy between the velocities must lie elsewhere.

* This work was supported by a grant from the Defense Research Board of Canada.
[1] L. Essen, Nature **159**, 611 (1947).
[2] C. I. Aslaskan, Nature **164**, 711 (1949).

N3. Electromagnetic Waves in Bounded Magneto-Ionic Media. BENJAMIN LAX.—The behavior of high frequency electromagnetic waves in ionized gases in the presence of an external magnetic field presents a dual problem of which only one aspect has been discussed in the literature. The first, solved by Appleton,[1] Hartree[2] and others, concerns the derivation of the propagation constant or the complex index of refraction when the frequency is assumed. The second involves the determination of the complex frequency when the value of the propagation vector is fixed or limited as it might be when the ionized medium is in a finite cavity or in a waveguide. The anisotropic properties of the magneto-ionic medium are responsible for the ordinary and extraordinary modes of propagation in one case and give rise to multiple resonant frequencies for a given mode in the other. Suitable approximations of uniform and moderate electron densities together with small collision frequencies are assumed for mathematical simplicity in order to obtain the theoretical results.

[1] E. V. Appleton, U.R.S.I. Reports, Washington (1927).
[2] D. R. Hartree, Proc. Camb. Phil. Soc. **25**, 47 (1929).

N4. Diffusion in the Ionosphere. M. H. JOHNSON AND E. O. HULBURT, *Naval Research Laboratory.*—It is assumed that the balance between rate of production of ions by monochromatic solar radiation and loss of ions by recombination and diffusion determines the ionic density in the atmosphere. The resulting non-linear differential equations have been integrated on the NRL Reac computer. Diffusion broadens the ionic density curve and shifts its maximum downward. The first effect changes the relations between real and virtual heights, and the second effect modifies the dependence of the height of the ionized region on the solar zenith angle. It was of interest to find that the relation between maximum ionic density and solar zenith angle was practically unchanged by diffusion (less than 20 percent). The influence of the magnetic field of the earth is taken into account.

N5. Extrapolation of the Geomagnetic Potential. C. J. SWIFT, *University of Pennsylvania.*—Recent theories place the source of the earth's magnetic field inside the core.[1] If there are no sources between the boundary of the core and the outer surface, the extrapolation of the surface field down to the core is possible by potential theory. Using conventional spherical harmonic analysis of the surface field, the series converges slowly. If we express the surface field in a limited region by means of surface harmonics which have a prescribed circle as a nodal line, we obtain more rapid convergence. These may be extrapolated down using solutions of Laplace's equation for a conical region. By this method we were able to obtain a lower limit for the secular variation at the boundary of the core. This is quite large, about one-half gauss per century. When we know the field and its time variation at the surface of the core we can set up an equation connecting fluid velocity with these quantities. This gives no unique solution, but considerable information. We obtained a lower limit of 0.04 cm/sec. for the surface velocity, lower than expected from other estimates.

[1] W. M. Elsasser, Rev. Mod. Phys. **22**, 1 (1950).

N6. Rapid Scanning Mass Spectroscope. WILLARD H. BENNETT, *National Bureau of Standards.*—The non-magnetic radiofrequency mass spectrometer is being developed for the rapid scanning of mass spectra. Methods have been developed for sweeping twice a second through masses ranging from 10 to 50 and presenting the observed mass components on a cathode-ray oscilloscope. The radiofrequency potential is modulated 10 percent at 1 kc and the 1-kc a.c. current received at the collecting electrode is amplified with an a.c. amplifier tuned to the modulation frequency. A fixed radiofrequency is used and the principal d.c. ion accelerating voltage is swept from 50 to 250 volts twice a second. The large inherent sensitivity of this kind of mass spectrometer tube makes it possible to use a.c. current amplifiers with short enough

relaxation constants to permit the rapid scanning of any mass ranges extending over a factor of five.

N7. Mass Spectra of Isotopic Hydrogen Molecules. FRED L. MOHLER, VERNON H. DIBELER, E. J. WELLS, JR., AND R. M. REESE.—The mass spectra of H_2, HD, D_2, HT, and T_2 have been measured with a Consolidated mass spectrometer with 50 volts ionizing voltage and with a magnetic field requiring 3800 volts to focus H^+. For H_2, D_2, and T_2 the following ratios were obtained: $H^+/H_2^+=0.0201$, $D^+/D_2^+=0.0096$ and $T^+/T_2^+=0.0061$. Sensitivities (current per unit pressure) for the molecule ions were 20.0, 19.5, and 17.8. For HD and HT the ratios were $H^+/HD^+=0.0096$, $D^+/HD^+=0.0097$, $H^+/HT^+=0.0085$, and $T^+/HT^+=0.0068$. Sensitivities for the molecule ions were 21.2 and 20.9. The HD pattern is based on spectra of pure HD fractionated by A. Fookson, P. Pomerantz, and E. H. Rich and the ratio D^+/HD^+ is an upper limit assuming H_2^+ is absent. Patterns for T_2 and HT were computed from two samples containing 91 and 37 atomic percent T in equilibrium. Theoretical values for the ratios of atom ions to molecule ions can be computed for ionization into the lowest state of the molecule ion and values are lower than observed by amounts ranging from 0.0015 to 0.0036. This is because ionization at 50 volts produces some ions from the repulsive states of the molecule ion.

N8. Mass Spectra of $C^{13}O_2$ and $C^{13}O$. V. H. DIBELER, E. J. WELLS, JR., AND R. M. REESE.—Mass spectra of $C^{13}O_2$ and $C^{13}O$ were obtained with a Consolidated mass spectrometer using conventional procedures. The CO_2 was evolved by H_2SO_4 on Eastman Kodak $BaCO_3$ containing 54 atom percent C^{13}. A portion of the CO_2 was completely reduced to CO with zinc. The peaks due to the ions containing C^{12} and C^{13} atoms were nearly of equal size, consequently the mass spectra of the isotopic molecules could be obtained from the same record. Corrections were made for oxygen isotopes. For CO_2, the ratio of the ions $C^{13}/C^{13}O_2$ was 0.0542 compared with the $C^{12}/C^{12}O_2$ ratio of 0.0564. The $C^{13}O/C^{13}O_2$ ratio was 0.0824 compared with the $C^{12}O/C^{12}O_2$ ratio of 0.0868. For CO, the $C^{13}/C^{13}O$ ratio was 0.0514 compared with the $C^{12}/C^{12}O$ ratio of 0.0540. The sensitivities of the isotopic molecule ions agreed within one percent. Thus, the frequency of rupture of a $C^{12}-O^{16}$ bond is approximately five percent greater than that of a $C^{13}-O^{16}$ bond. This is in essential agreement with the isotope effect reported by Thode and co-workers in the decomposition of oxalic acid. A comparable but less accurate difference was observed between the $C^{12}-O^{16}$ and $C^{14}-O^{16}$ bonds in CO_2 containing four atom percent C^{14}.

N9. Degradation of Different Molecular Weight Polyisobutylenes on Shearing in Solution. A. B. BESTUL AND H. V. BELCHER, *National Bureau of Standards.*—Five, ten, and fifteen weight percent solutions, in *o*-dichlorobenzene, of ten different unfractionated polyisobutylenes ranging in viscosity average molecular weight from 50,000 to five million have been investigated for decrease of viscosity during repeated shearing through a capillary at 40°C and a nominal rate of shear of 66,000 sec.$^{-1}$. For average molecular weights below 400,000 no reduction was observed at any of these concentrations. For average molecular weights above 400,000, reductions were observed at all of these concentrations. At each concentration the apparent viscosity observed during the first pass of a solution through the capillary rose sharply with increasing average molecular weight. For average molecular weights above 400,000 the apparent viscosity observed suring the fiftieth pass of a solution through the capillary rose but little with increasing molecular weight. Viscosities of dilute (0.1 to 0.5 percent) solutions prepared from the 10 percent solution of two million average molecular weight polyisobutylene both before and after shearing the 10 percent solution indicate that the shearing resulted in an average molecular weight decrease of at least 20 percent in this case. These results support the view that the decrease of viscosity of shearing is associated with a degradation of the polymer molecules.

N10. Diffusivity of Water Vapor in Some Common Gases. F. A. SCHWERTZ AND JEANNE E. BROW, *Mellon Institute.**—From the measured rates of diffusion of water vapor into pure hydrogen, helium, methane, ethylene, nitrogen, oxygen, and carbon dioxide, the mutual coefficients of diffusion have been determined. Measurements were made at 34°, 56°, and 80°C and at atmospheric pressure employing the technique of Stefan.[1] The experimental diffusion coefficients were all several percent larger than those calculated by means of the semi-empirical equations of Arnold[2] and Gilliland.[3]

* Work supported by Koppers Company, Inc.

[1] Stefan, Ann. d. Physik **41**, 723 (1890).
[2] Arnold, Ind. Eng. Chem. **22**, 1091 (1930).
[3] Gilliland, Ind. Eng. Chem. **26**, 681 (1934).

N11. On the State of Conductivity Created in a Liquid Isolator under the Action of an Electric Dispersive Field. OLEG YADOFF, *Columbia University.*—An electric current is produced in a circuit by a suitable voltage connected to a point form pole suspended in air, the other pole being a metallic flat-bottomed reservoir filled with isolating liquid. The magnitude of current is a function of: the kind of isolators, voltage applied, distance between poles and thickness of liquid. A very peculiar phenomenon is observed then on the surface of the isolator: on water a kind of turbulence is formed, physically resembling surface Hertzian waves. In mineral oils, whirlings of strictly polygon shape are formed. It is these whirlings which bridge the insulator. Many photographs of phenomena prove the physical reality of these whirlings, which have a peculiar likeness to the thermoconvective whirlings of Tyndall and Bernard. The whirlings can be replaced by surface extension by applying suitable voltage. A kind of star is then formed; it grows instantly and throws some of the oil from reservoir if its walls are slanted. If they are vertical, instead descending whirlings are formed. Only when electrostatic field is used is this phenomenon observed.

N12. Sitting Time of Molecules on a Hot Wire Detector. D. T. F. MARPLE AND HENRY LEVINSTEIN, *Syracuse University.*—The experiments[1] for the determination of the velocity distribution of molecules in a molecular beam have been modified to determine the sitting time of alkali halide molecules on a hot tungsten wire. Atoms from an oven are pulsed by a rotating shutter disk. Because of the velocity distribution of molecules in the beam the pulse widens in transit between shutter and detector. The voltage across a resistance in the detector circuit, permits observation of the widened pulse on a cathode-ray oscillograph. Simultaneously with the pulsing of the molecular beam, a light beam from a source directly below the oven is being pulsed and detected by a photo-cell. After amplification the photo-cell output, when applied to the *Z* axis of the oscilloscope, locates the time when atoms pass through the shutter. The time interval between hot wire detector pulse and photocell pulse thus gives the molecular transit time from shutter to hot wire plus the molecular sitting time on the wire. The sitting time of the molecules on the wire is then determined by varying the distance between shutter and detector and extrapolating this curve to zero distance.

[1] I. L. Kofsky and Henry Levinstein, Phys. Rev. **74**, 500 (1948).

N13. Thermal Properties of Diphenyl Ether. G. T. FURUKAWA, R. E. MCCOSKEY, R. S. JESSUP, AND R. A. NELSON, *National Bureau of Standards* (To be presented by G. T. Furukawa).—The specific heat of diphenyl ether was measured in the temperature range 14 to 360°K using an adiabatic

vacuum-type calorimeter. A Debye function was used to extrapolate the specific heat below 14°K. The entropy, free energy, and enthalpy with respect to the solid at absolute zero were calculated. The heat of fusion was found to be 17,210 ±5 abs. j./mole and the triple point 300.03±0.01°K. The heat of combustion was determined in a bomb calorimeter. The standard heat, free energy, and entropy of formation at 25°C were calculated. $\Delta H_c° = -6119$ abs. Kj./mole. $\Delta H_f° = -32.13$ abs. Kj./mole. $\Delta S_f° = -590.0$ abs. j./mole deg $\Delta F_f° = 143.8$ abs. Kj./mole.

FRIDAY MORNING AT 10:00

Lisner Auditorium

(D. M. DENNISON presiding)

Microwave Molecular Spectra and Pressure-Broadening

O1. The Microwave Absorption Spectrum of Oxygen at Low Pressures.* J. H. BURKHALTER, R. S. ANDERSON, W. V. SMITH, AND W. GORDY, *Duke University.*—Using a Zeeman modulation microwave spectrograph, we have observed 25 absorption lines of oxygen in the 5-mm wave region, 19 of which have been measured with a frequency standard. The line width parameter $\Delta\nu$ was observed for three of these, and found to be $\sim$.021 cm^{-1}/atmosphere for high K, but to increase for low K, being .053 cm^{-1}/atmosphere for $\nu_-(3)$. The latter breadth agrees with theoretical predictions from polarizability interactions. If it is assumed that the collision duration is comparable to a rotational period for the higher K lines, the decrease of $\Delta\nu$ with increasing K is also explained. The data suggest a collision duration of about 10^{-12} sec. Schlapp's formulas[1] are found to be inadequate. The quantity $\nu_+(K) + \nu_-(K-2)$, or $2\lambda+\mu$ by Schlapp's formula, increases approximately quadratically with K. It appears that the correction factor applies to the $\nu_-(K)$ formula alone, and is not symmetrical in the two series.

* Supported by a contract with Air Force Cambridge Research Laboratories.

[1] R. Schlapp, Phys. Rev. **51**, 342 (1937).

O2. Effect of Fermi Resonance on Rotation-Vibration Interaction in OCS and OCSe.* W. LOW AND C. H. TOWNES, *Columbia University.*—Rotational frequencies of a linear XYZ molecule for an excited vibrational state are usually written

$$\gamma = 2J[B_e - \alpha_1(v_1+\tfrac{1}{2}) - \alpha_2(v_2+1) - \alpha_3(v_3+\tfrac{1}{2})]$$

where the α's are the vibration-rotation constants and allow for changes in B due to vibrations. However, measurements of the α's for the various vibrational states in OCS and OCSe show little consistency. These discrepancies are explained within experimental accuracy as due to interactions between adjacent vibrational levels[1] with quantum numbers v_1, v_2, v_3, and $v_1\pm1$, $v_2\pm2$, v_3. This is the "Fermi resonance" first found in CO_2. The interaction energies W_{ni} and the unperturbed α's for OCS are $\alpha_1 = 20.55$, $\alpha_2 = -10.59$ Mc, $W_{ni} = 40$ cm^{-1} and for OCSe they are $\alpha_1 = 14.01$, $\alpha_2 = -6.88$ Mc, $W_{ni} = 45.7$ cm^{-1}. Resonance of this type in ICN has been found to be much smaller.

* Work supported jointly by the Signal Corps and ONR.

[1] We are grateful to Professor R. C. Lord for information on the OCSe vibrational frequencies, and to Dr. W. Benedict for a discussion of these effects.

O3. Microwave Spectra of the Methyl Mercuric Halides.* WALTER GORDY AND JOHN SHERIDAN,** *Duke University.*—Several rotational transitions have been observed for methyl mercuric chloride, bromide, and iodide. A large number of lines was found for each transition. These arise from the nuclear coupling of the halogen and from several different isotopic weights of mercury which are present. In the chloride the spectrum of these isotopes was readily identified, and the nuclear quadrupole splitting of Hg^{201} was observed. The absence of a hyperfine structure for the other Hg isotopes supports the spin value of $\frac{1}{2}$ for Hg^{199} and the expected spin of zero for $Hg^{198, 200, 202, 204}$. The analysis of the data is not yet complete.

* Supported by contract with the Air Force Cambridge Research Laboratories.

** On leave from the Department of Chemistry, University of Birmingham, Birmingham, England.

O4. Microwave Spectrum of Methyl Bromo-Acetylene.* JOHN SHERIDAN** AND WALTER GORDY, *Duke University.*—The $J=8\rightarrow9$, $9\rightarrow10$, and $11\rightarrow12$ transitions of $H_3C-C\equiv C-Br^{79}$ and the $J=8\rightarrow9$ and $11\rightarrow12$ transitions of $H_3C-C\equiv C-Br^{81}$ have been observed. The moments of inertia, I_B, are 537.07×10^{-40} g/cm^2 and 540.96×10^{-40} g/cm^2 respectively. The spectra show a well resolved hyperfine structure which is being analyzed.

* Supported by contract with Air Force Cambridge Research Laboratories.

** On leave from the Department of Chemistry, University of Birmingham, Birmingham, England.

O5. Microwave Spectrum of Methyl Cyanide and its Isotopic Modifications. D. K. COLES, W. E. GOOD, AND R. H. HUGHES, *Westinghouse Research Laboratories.*—The $J=1\rightarrow2$ transitions of CH_3CN, which fall in the region of 37,000 Mc, were first studied by Ring, Edwards, Kessler, and Gordy. An intense triplet which they observed has recently been considered by Nielsen (in a paper on l-type doubling in polyatomic molecules) as due to the molecules in the first excited state of the ν_8 vibration. Our measurements of the first and second order Stark effects in this spectrum confirm Nielsen's theory. We were able to determine the l-type doubling for the states $J=1$ and $J=2$ separately, since the presence of an electric field allows the observation of lines which are ordinarily forbidden. A weak doublet, a triplet, and a single line, were also found. These are attributed to molecules in the vibrational states $V_8=2$, $V_7=1$, $V_4=1$. Three other isotopic species of this molecule have been prepared and studied. Preliminary measurements yield the following spectroscopic constants.

$B_0(CH_3CN) = 9{,}198.70$ mc	$\alpha_4 = 46.3$ mc
$B_0(C^{13}H_3CN) = 8{,}933.15$ mc	$\alpha_7 = 5.2$ mc
$B_0(CH_3C^{13}N) = 9{,}194.20$ mc	$q_7 = 4.5$ mc
$B_0(CH_3CN^{15}) = 8{,}921.81$ mc	$\alpha_8 = -22.5$ mc
$\mu = 3.97$ Debye units	$q_8 = 17.7$ mc.

O6. Microwave Spectra and Molecular Constants of CD_3NC and CD_3CN.* RALPH TRAMBARULO AND WALTER GORDY, *Duke University.*—The measurements of Kessler, Ring, and Gordy on the ordinary methyl isocyanide and aceto-

nitrile have been supplemented by measurements on deuterated samples and on the compounds containing C^{13}. As a result the structural determinations of these molecules have been completed as follows: For methyl isocyanide, $\angle HCN = 109°9'$, $d_{CH} = 1.094A$, $d_{CN} = 1.427A$, and $d_{NC} = 1.167A$. For acetonitrile, $\angle HCC = 109°49'$, $d_{CH} = 1.092A$, $d_{CC} = 1.460A$, and $d_{CN} = 1.158A$. The nuclear coupling is -4.40 mc in acetonitrile and $< |0.5|$ mc in methyl isocyanide.

* Supported by a contract with Air Force Cambridge Research Laboratories.

O7. Microwave Spectrum of Bromoform and Phosphorus Tribromide. QUITMAN WILLIAMS* AND WALTER GORDY, *Duke University.*—The 14th, 15th, and 16th rotational transitions of $CHBr_3^{79}$ and $CHBr_3^{81}$ have been observed, and their hyperfine structure has been partially resolved. Measurements with a cavity wave meter yield 678.1×10^{-40} g/cm² and 683.7×10^{-40} g/cm² for the respective moments of inertia, I_B. Similar measurements on the 18th, 19th, 20th, and 21st rotational lines of PBr^{79} and on the 20th, 21st, and 22nd lines of PBr^{81} yield 841.9×10^{-40} g/cm² and 860.9×10^{-40} g/cm² for their respective moments of inertia. More precise measurements are being made.

* Texas Company Fellow.

O8. Microwave Collision Diameters.* RAYDEEN R. HOWARD AND WILLIAM V. SMITH, *Duke University.*—The diameters of fifteen polar and non-polar gases for collisions with ammonia are obtained from measurements of the pressure broadening of the ammonia 3—3 inversion line in the mixed gases at low pressures. A type 2K50 klystron and magic tee supply microwave power to two absorption cells. In addition to the usual sawtooth sweep, the klystron is modulated at 100 kc and 2 mc. Delection of the 100-kc component through one cell gives an oscilloscope display of the first derivative of the line-shape. From pressure and relative intensity measurements at constant line breadth in pure ammonia and dilute ammonia mixtures the collision diameters are obtained. The other cell contains ammonia at low pressure. Detection of the 2-mc component through this cell yields markers of constant spacing which were used to maintain a constant frequency scale and to look for pressure shifts of resonant frequency.

* Supported by a contract with the Air Force Cambridge Research Laboratories.

O9. The Pressure Shift of the Inversion Frequency of Ammonia. A. H. NETHERCOT, JR. AND C. W. PETERS, *University of Michigan.*—In order to fit the microwave line shape data at high pressures by the Van Vleck-Weisskopf pressure broadening formula, it has been assumed by Weingarten that the inversion frequency of ammonia approached zero for pressures above 115 cm.[1] The resolution of the ν_1 band at 3μ—which results from the same type of inversion frequency transition plus a vibrational transition—reveals no such large shift. The infra-red data are consistent with the assumptions that no change in the splitting of the inversion doublet (1.6 cm^{-1}) occurs and that the line breadth is roughly proportional to pressure up to one atmosphere ($\Delta\nu/p = 0.01$ cm^{-1}/cm) and then rises somewhat less rapidly with pressure at two atmospheres. The total absorption is proportional to pressure. Great accuracy in these constants is not attained, but the results clearly rule out a large shift in frequency such as that employed previously in the interpretation of the high pressure microwave line shape data.

[1] Irving R. Weingarten, Columbia Radiation Laboratory Report (May 1, 1948).

Post-Deadline Papers, if Any

FRIDAY AFTERNOON AT 2:15

Lisner Auditorium

(H. C. TORREY presiding)

Hyperfine Structure in Radiofrequency Region; Paramagnetic and Anti-Ferromagnetic Resonance.

P1. Radiofrequency Transitions in a Tapered Electric Field. JOSHUA GOLDBERG AND PETER G. BERGMANN, *Syracuse University.*—In an experiment measuring the nuclear quadrupole interaction in C_sF, J. W. Trischka observed a broadening of the spectral lines in strong fields which he attributed to inhomogeneities in the fields.[1] We have calculated the probability that a molecule in a tapered (inhomogeneous) electric field will undergo a transition between two states of different spatial quantization when stimulated by a radio frequency field. In the calculations we considered diatomic molecules with a molecular dipole moment but without a nuclear quadrapole moment. By taking a linear combination of the solutions for the zero taper case, we were able to obtain differential equations for the probability amplitudes, the solutions of which reduce to the usual ones in the absence of a taper. Using a linear taper and making the assumption that the taper does not alter the line shape very much, we obtained an expression for the probability amplitudes in closed form. The solution shows a broadened line profile, but any shift of the resonance peak was less than the accuracy of the approximation. The approximation is valid for tapers which cause a broadening up to 20 percent.

[1] J. W. Trischka, Phys. Rev. **74**, 718 (1948).

P2. The Optical Detection of Radio-Frequency Resonance.* J. BROSSEL,** P. SAGALYN,*** AND F. BITTER, *M.I.T.*—The measurement of Zeeman patterns in weak fields is accomplished most effectively by the resonance absorption of radio-frequency energy. Optical means of detecting resonance have recently been discussed.[1] The predicted effects have been shown to be smaller than originally calculated and not actually observable. We have used successfully a method, recently suggested.

Mercury vapor in a magnetic field of the order of 100 gauss is illuminated perpendicularly to the field with radiation $\lambda = 2537$, polarized parallel to the field: only the π component, corresponding to a transition with $\Delta m = 0$ from the ground state $^1S_0$ to the excited state $^3P_1$ is absorbed and re-emitted. When transitions are induced within the excited state to the levels $m = \pm 1$ by means of the radio frequency field of the

correct frequency (~150 megacycles in our experiment) the radiation re-emitted contains σ as well as π components—consequently the intensity emitted parallel to the field is increased.

Radio frequency resonance for the isotopes of even mass and for Hg^{199} were observed at the expected frequencies and fields.

* This work has been supported in part by the Signal Corps, the Air Materiel Command and ONR.
** Joint fellow of Spectroscopy Laboratory and Laboratory for Nuclear Science and Engineering.
*** A.E.C. predoctoral fellow.
[1] F. Bitter, Phys. Rev. **76**, 833 (1949).

P3. Nuclear Magnetic Moment of Sb^{121}.* THOMAS L. COLLINS,** *University of British Columbia* (Introduced by G. M. Volkoff).—Weak signals for Sb^{121} have been observed on a recording magnetic resonance spectrometer. The frequency relative to sodium is $\nu Sb^{121}/\nu Na^{23} = 1.0041 \pm .0003$ which gives a value for the magnetic moment $\mu Sb^{121} = 3.730 \pm .002 \mu_N$ (with diamagnetic correction). This compares excellently with Crawford's spectroscopic value of $3.7 \mu_N$.[1] The measurements were made at a frequency of 7 mc in a proton stabilized field of about 6000 gauss. The frequency of a weak oscillator-detector (autodyne) was swept by a mechanical drive over both signals. The antimony absorption has a signal to noise ratio of about ten and a width of 7 kc between points of maximum slope while the much larger sodium signal has a width of less than 1 kc. The antimony shows a slight asymmetry which is not present in the sodium signal. The sample was 1 ml of concentrated $SbCl_3$ solution with a small amount of NaCl added.

* Work supported by the National Research Council of Canada.
** Holder of National Research Council of Canada Fellowship.
[1] M. F. Crawford and S. Bateson, Can. J. Research **10**, 693 (1934).

P4. Microwave Measurements on the Stable Selenium Isotopes in OCSe.* S. GESCHWIND, H. MINDEN, AND C. H. TOWNES, *Columbia University*.—From a re-examination of the $J=2-3$ transition[1] in OCSe, the relative masses of the stable Se isotopes have been determined, and an upper limit of 0.002×10^{-24} cm^2 assigned to the quadrupole moments. Frequency differences of the six selenium lines in $O^{16}C^{12}Se$, corresponding to the six naturally occurring Se isotopes, were measured to an accuracy of 15 kc or better and from them the relative Se masses were obtained. The variation of mass defect with isotopic number is in good agreement with the Bohr-Wheeler formula. The odd-even mass variation found is 0.0018 m.u. Although the OCSe lines were obtained as narrow as 60 kc, no noticeable asymmetry or splitting suggestive of hyperfine structure was observed in Se^{77} or in any other Se isotopes, in agreement with earlier work.[1] This gives an upper limit of 1 mc to the quadrupole coupling constant or 0.002×10^{-24} cm^2 to the quadrupole moment. Such a small quadrupole moment is puzzling in view of the measurements on the optical hyperfine structure which indicate a spin for Se^{77} of 5/2 or greater.[2]

* Work supported jointly by the Signal Corps and ONR.
[1] Strandberg, Wentink, and Hill, Phys. Rev. **75**, 827 (1949).
[2] J. E. Mack and O. V. Arroe, Phys. Rev. **76**, 160 (1949) and private communication.

P5. Hyperfine Structure and Nuclear Specific Heat of Copper. J. A. BRINKMAN AND C. KIKUCHI, *Michigan State College*.—The h.f.s. energy levels of Cu^{++} for the lowest electronic state in a tetragonal crystalline electric field and zero magnetic field were calculated to the first approximations. Using the nuclear specific heat constant, $CT^2/k = 1.1 \times 10^{-4}$ cm^{-1}, measured by Benzie and Cooke,[1] based on Gorter's[2] paramagnetic relaxation method, we have been able to infer a value of 0.019 cm^{-1} as an upper limit for the h.f.s. splitting factor, a. This is in fair agreement with Ritschl's[3] spectroscopic value of 0.022 cm^{-1} for the unionized $^2D_{5/2}$ state of Cu, but is somewhat larger than Penrose's[4] value of 0.005 cm^{-1}, obtained by microwave measurements. The temperature dependence of the nuclear specific heat was calculated down to about 0.001°K. If other effects are negligible or constant in this range, the maximum in the nuclear specific heat curve should occur at about 0.002°K.

[1] R. J. Benzie and A. H. Cooke, Nature **164**, 837 (1949).
[2] C. J. Gorter, *Paramagnetic Relaxation* (Elsevier Publishing Company, Inc., New York, 1947).
[3] R. Ritschl, Zeits. f. Physik **79**, 1 (1932).
[4] R. P. Penrose, Nature **163**, 992 (1949).

P6. Effective g-Values of Various Paramagnetic Ions.* YU TING, ROY C. WEIDLER, AND DUDLEY WILLIAMS, *The Ohio State University*.—The microwave magnetic resonance absorption spectra of several paramagnetic salts have been studied. The experimental method involved the measurement of the transmission of 3.2-cm radiation through a resonant cavity containing a single crystal or powdered sample of the salt being studied. The resonant cavity was placed between the pole pieces of a large electromagnet and the variation of transmitted power with variations of the magnetic field strength was observed. From the frequency of the radiation and the magnetic field strength corresponding to maximum absorption, it is possible to determine the effective g-value for the paramagnetic ion in each salt. The results obtained for Mn^{++}, Cu^{++}, Ni^{++}, Fe^{+++}, and Cr^{+++} are in essential agreement with calculated values for spin-only ions. From the peak shapes it is possible to estimate the effects of interaction between the neighboring paramagnetic ions and between the ions and the crystalline fields.

* This work is related to research work done under a contract between the Geophysical Directorate of the Air Force Research Laboratory, Cambridge, Mass. and The Ohio State University Research Foundation.

P7. Paramagnetic Resonance in Single Crystals of the Manganous Halides. ALDEN H. RYAN, *Naval Research Laboratory*.—Measurements of the paramagnetic resonance spectrum of $MnCl_2 \cdot 4H_2O$ and $MnBr_2 \cdot 4H_2O$ have been made on single crystals of these salts, as a function of orientation of the crystal with respect to the static magnetic field. The measurements were made at a wave-length of 3.2 cm, using a magic T microwave bridge and superheterodyne detector. The measurements were carried out over a temperature range from about 80°K to about 300°K. The results are discussed in terms of the spectrum predicted by Kittel and Luttinger (Phys. Rev. **73**, 162 (1948)) and in relation to the anisotropy of the static magnetic susceptibility of these salts, as discussed by Van Vleck and Penney (Phil. Mag. **17**, 961 (1934)) and Krishnan and Banerjee (Trans. Roy. Soc. **A235**, 343 (1936)).

P8. Magnetic Resonance Absorption in Chromium Sesquioxide.* E. P. TROUNSON, D. F. BLEIL, AND L. R. MAXWELL, *U. S. Naval Ordnance Laboratory*.—Magnetic resonance absorption at microwave frequencies (3.2 cm) has been measured for Cr_2O_3 in the temperature range from room temperature to 70°C which includes a transformation from an antiferromagnetic to a paramagnetic state; the Curie temperature is reported by two different authors to be 34°C[1] and 47°C.[2] At 70°C the absorption is strong showing a single maximum coming at a field strength of about 3300 oersteds, as expected on the basis of paramagnetic absorption. As the temperature is lowered there is no large change in the height of the absorption peak until about 37°C is reached where the height drops precipitously to a value slightly greater than the background at 30°C. This sudden decrease in height of the absorption peak is attributed to the change of Cr_2O_3 from paramagnetism to antiferromagnetism.

* Supported in part by the ONR.
[1] K. Honda and T. Sone, Sci. Rep. Tohoku Imp. Univ. **3**, 223 (1914).
[2] G. Foex and M. Graff, Comptes Rendus **209**, 160 (1939).

P9. Interpretation of Magnetic Resonance Absorption in Antiferromagnetic Materials.* D. F. BLEIL AND R. K. WANGSNESS, *U. S. Naval Ordnance Laboratory.*—The experimental result reported in the previous abstract can be understood in terms of the local fields existing in antiferromagnetic materials. Antiferromagnetic materials are characterized by an exchange coupling which prefers antiparallel alignment of the spins rather than the usual parallel alignment found in ferromagnetism. Above the Curie temperature the usual paramagnetic absorption should occur. Below the Curie temperature the effective field ($\mathbf{H}_{\text{eff}}^{\pm}$) at any one atom will be modified by the spontaneous magnetization ($\mathbf{S}_0$) of its nearest neighbors which are aligned antiparallel. In contrast to the ferromagnetic case the field due to the spontaneous magnetization need not be parallel to the direction of the magnetic vector ($\mathbf{M}$). We have, therefore, $d\mathbf{M}/dt=\gamma\mathbf{M}\times\mathbf{H}_{\text{eff}}$[1] where

$$\mathbf{H}_{\text{eff}}^{\pm}=\mathbf{H}_a+2Jzg^{-1}\beta^{-1}(\mp\mathbf{S}_0)+2Jz\mathbf{M}/Ng^2\beta^2. \quad (2)$$

At the Curie temperature the spontaneous magnetization is zero and increases rapidly as the temperature is decreased. The resonant frequency increases with the internal field and rapidly exceeds the range of microwave equipment. Therefore, one could not expect any appreciable absorption below the Curie temperature at microwave frequencies.

* Supported in part by the ONR.
[1] C. Kittel, Phy. Rev. **73**, 155 (1948).
[2] J. H. Van Vleck, J. Chem. Phys. **9**, 85 (1941).

FRIDAY AFTERNOON AT 2:15

Department of Interior Auditorium

(C. C. LAURITSEN presiding)

Nuclear and Electronic Scattering; Pair-Production

Q1. Energy Dependence of Proton-Proton Scattering over the Interval of 19 to 32 Mev.* BRUCE CORK, *University of California, Berkeley.*—Measurements have been made of the absolute differential cross section of proton-proton scattering at 90° in the center of mass system. The energy of the incident protons from the linear accelerator was varied from 32 Mev down to 19 Mev and an energy interval of ±0.5 Mev was selected by means of a deflecting magnet. Apparatus using proportional counters and a triple coincidence method was used to reduce the background. Measurements were made simultaneously using the apparatus[1] for measuring the angular distribution at 31.8 Mev, and a single charge integrator for collecting the incident proton beam. The cross section at 90° center of mass varies approximately as the reciprocal of the energy of the incident protons. Data will be presented to show this dependence.

* This work was sponsored by the AEC.
[1] Richman, Johnston, and Cork, UCRL-482.

Q2. Coherent Neutron-Proton Scattering by Liquid Mirror Reflection. D. J. HUGHES, *Brookhaven National Laboratory,* AND M. T. BURGY AND G. R. RINGO, *Argonne National Laboratory.*—An accurate determination of the coherent neutron-proton scattering amplitude, a_H, is important because of the direct connection between a_H and the fundamental nuclear force constants. We have recently[1] obtained a value for a_H of $(-3.75\pm0.03)\times10^{-13}$ cm by a comparison with carbon, involving critical reflection of neutrons from a liquid hydrocarbon ($C_{12}H_{18}$) mirror. The experiment has now been repeated, using various liquids and a range of neutron wavelengths, in order to search for systematic errors. With $C_{12}H_{18}$, the unbalanced coherent scattering amplitude (a_C is positive and slightly larger than $1.5a_H$) was determined from the measured wave-length at a fixed incident angle (about 5 minutes). The present method consists of a determination of the particular C−H ratio for which the amplitude is zero, at which ratio the reflected intensity is zero for all incident angles. The reflected intensities from liquids of different C−H ratios, some of which are mixtures, are measured at different angles, and it is then a simple matter to extrapolate to the C−H ratio corresponding to zero amplitude. The values of a_H obtained with different liquids and neutron wave-lengths are in agreement with the $C_{12}H_{18}$ result and make systematic errors unlikely.

[1] Hughes, Burgy, and Ringo, Phys. Rev. **77**, 291 (1950).

Q3. Neutron-Proton Scattering at 27 Mev. J. E. BROLLEY, JR., J. H. COON, AND J. L. FOWLER, *Los Alamos.*—Neutrons of average energy of 27.4 Mev, and with a maximum spread in energy of one Mev, were produced by bombarding gaseous tritium with deuterons accelerated by the cyclotron. Recoil protons from a polyethylene radiator 0.02 in. thick were observed at 0, 15, 30, 37.5, 45, and 52 deg. in the laboratory system. Quadruple coincidence counting of the protons was performed with a fourfold proportional counter system. Sufficient aluminum absorber was inserted between the two remote counters to absorb low range background particles. The neutron yield was monitored by the charge incident on the target as measured by a condenser type integrator. Angular distributions were obtained with two series of runs: one with the radiator at 5.7 in., and the other at 15.3 in., from the center of the target. The two sets of data agree and show that the distribution is definitely anisotropic. The ratio of the differential scattering cross section at 180 deg. to that at 90 deg. in the center of mass system is 1.3.

Q4. D−P Scattering for 10.4-Mev Deuterons. J. C. ALLRED, AND LOUIS ROSEN, *Los Alamos.*—A nuclear multiple plate camera has been utilized to measure the differential cross section for D−P scattering at 10.35±0.10-Mev deuteron energy. The camera contains its own collimating system for the incident as well as the scattered particles and no windows are utilized from the time the beam enters the first collimating slit until it emerges from the camera to enter a faraday cup. The solid angle subtended by each detector at the reaction volume is determined by an accurately machined slit system. Data will be presented of tests on this camera using the well known differential cross sections for p−p and p−He^4 scattering in the 3-Mev proton energy region. The cross section in barns for some of the center of mass angles investigated are: 50°, 0.163±0.004; 60°, 0.141±0.004; 65°, 0.126±0.003; 70°, 0.112±0.003; 75°, 0.100±0.0026; 80°, 0.0902±0.0024; 85°, 0.0862±0.0021; 90°, 0.0707±0.0018; 100°, 0.0604 ±0.0015; 110°, 0.0543±0.0013; 120°, 0.0576±0.0015; 130°, 0.0742±0.0020; 135°, 0.0809±0.0025; 140°, 0.107±0.003.

Q5. Scattering of 250-Mev Protons from Nucleons within Nuclei.* G. M. TEMMER, *University of Rochester.*—The circulating 250-Mev proton beam of the Rochester cyclotron was made to impinge upon thin internal targets of aluminum, copper, and lead. The emerging protons were sorted according

to their momenta and scattering angles by the magnetic field of the cyclotron and detected by nuclear emulsions along a radial probe, a method used in elastic p−p scattering.[1] Since to a given position and given entrance angle into the emulsion there uniquely correspond a definite proton energy and scattering angle, it is possible to determine both an angular distribution of scattered protons and proton energy distributions at fixed scattering angles, both of which are expected to yield information concerning the behavior of nucleons in nuclei. Some preliminary qualitative results indicate that single "elastic" proton-nucleon encounters account for an appreciable fraction of protons scattered from aluminum for scattering angles between 45° and 60° (laboratory), but for less from the heavier elements. This is reasonable in view of the mean free paths in nuclear matter for both incident and "elastically" scattered protons (lowest energy observed ~60 Mev). Further measurements are in progress, especially at larger scattering angles where internal nuclear effects are expected to show up more decisively.

* This work was assisted by the joint program of the ONR and the AEC.
[1] O. A. Towler, Jr. and C. L. Oxley, Bull. Am. Phys. Soc. **25**, 1, 19 (1950) (New York Meeting).

Q6. Elastic and Inelastic Scattering* of 14-Mev Deuterons. KEITH BOYER AND HARRY GOVE, *M.I.T.*—Energy spectra of inelastically scattered deutrons have been obtained for thin targets of a number of elements and angular distributions determined for the elastic group and inelastic groups in several of the targets. The elastic group in gold was found to obey the Rutherford law closely for angles less than about 50 degrees, while at greater angles it falls more rapidly. Fair agreement was obtained between the differential cross section of the elastic peak in gold at 20° computed from the Rutherford formula and the value measured by counting all the elastically scattered deuterons for an integrated beam current. The differential cross section for a number of individual groups was integrated over angle to obtain total cross sections.

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

Q7. Scattering and Capture of Protons by Aluminum. F. C. SHOEMAKER,* J. E. FAULKNER, S. G. KAUFMANN AND G. M. B. BOURICIUS, *University of Wisconsin.*—Thin films of aluminum were bombarded with protons from the Wisconsin pressure generator. By use of the techniques developed in preliminary work,[1] yield curves covering the region from 1.4 to 4.1 Mev were obtained for elastically scattered protons (resolution ~2 kev), alpha-particles (resolution ~6 kev), and gamma-radiation. These curves show a large number of resonance levels with widths ranging from ~30 kev to ~1.5 kev. The general level of the elastic scattering decreases from 1.4 to 2.0 Mev and then remains substantially constant. The alpha-yield, essentially zero between resonances, shows a general increase at resonance with increasing proton energy. The intensity of hard gamma-radiation at resonance apparently does not increase appreciably with increasing proton energy, but an intense, very soft (~1 Mev) component is found at high proton energies. Inelastically scattered protons and low energy alphas were found which, it is believed, account for this. All charged particle yields were observed at 165° in the laboratory system. This work was supported in part by the AEC and in part by the Wisconsin Alumni Research Foundation.

* Now at Princeton University, Princeton, New Jersey.
[1] Bender, Shoemaker, Kaufmann, and Bouricius, Phys. Rev. **76**, 273 (1949).

Q8. Electron-Electron Scattering. LORNE A. PAGE AND W. M. WOODWARD, *Cornell University.*—The differential cross section, for the scattering of negative β-rays by atomic electrons, has been measured for various values of the β-ray energy, E, and fractional-energy-transfer, v. A $Sr^{90}-Y^{90}$ source was used for the β-rays and thin foils of Nylon and collodion for the scatterer. A magnetic field is used to define the energy of the primary electron and the fractional-energy-transfer. Pairs of Geiger counters in coincidence are used to detect the scattered particles. Results to date for $\sigma(E, v)$ for $v=\frac{1}{2}$, in units of 10^{-24} cm^2 and per unit fractional-energy-transfer are:

E(Mev)	$(E, \frac{1}{2})$
0.47	3.4
0.85	1.5
1.16	1.1

The method will be extended to positron-electron scattering.

Q9. Elastic Scattering of 16.5-Mev Electrons.* E. M. LYMAN, A. O. HANSON, AND M. B. SCOTT, *University of Illinois.*—The electron beam from the 22-Mev betatron was focused to a 2-mm spot 4 meters from the betatron by a magnetic lens. It passed through a low pressure ion chamber and impinged upon thin foil targets at the center of an evacuated scattering chamber 20 in. in diameter. Scattered electrons were selected in angle by a Lucite aperture $\frac{3}{8}$ in.×2 in., analyzed and refocused by a 75° Nier type magnetic analyzer with 3 percent energy resolution, and detected by coincidence Geiger counters. Preliminary results for the scattering cross sections in barns per unit solid angle are shown in the table. R represents the ratios to values calculated by McKinley and Feshbach.

	Z	σ (30°)	R	σ (90°)	R	σ (150°)	R
C	6	0.13	0.94	0.0010	0.73	0.000044	0.77
Al	13	0.65	0.97	0.0051	0.75	0.00022	0.94
Cu	29	3.1	0.86	0.031	0.74	0.0013	0.86
Ag	47	9.6	0.92	0.104	0.75	0.0044	0.85
Au	79	30	0.88	0.37	0.45	0.021	0.38

The experimental values were corrected for the effect of small angle multiple scattering, (~10 percent at 30°). Absolute values are less accurate than relative values at the same angle.

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

Q10. Study of Electron-Electron Scattering.* GERHART GROETZINGER, LEWIS B. LEDER, FRED L. RIBE, AND MARTIN J. BERGER, *University of Chicago.*—In the course of various cloud-chamber investigations pictures of 98 electron-electron collisions were obtained, in which the primary electrons ranged in energy approximately from 0.05 to 1.7 Mev and the deflections (in the center of mass system) exceeded 32°. By means of a statistical test suitable for the systematic evaluation of rather heterogenous data, a comparison was made of our results with the theory of Møller (M), relativistic versions of the theories of Mott (MR) and Rutherford (RR) and the classical non-relativistic Rutherford theory (R). Our data discriminate definitely only against (R). When combined with 122 electron-electron collisions observed by Champion[1] they are consistent only with (M) or (MR), but insufficient to discriminate decisively between them.

* This research was assisted in part by the joint program of the ONR and AEC.
[1] F. C. Champion, Proc. Roy. Soc. **A137**, 688 (1932).

Q11. Correlation between the Polarization States of Annihilation Quanta. FRANK L. HEREFORD, *University of Virginia.*—Following the suggestion of Pryce and Ward[1] the polarization states of the two quanta emitted in annihilation of an electron-positron pair have been investigated by coincidence detection of the photoelectrons ejected by the quanta at various azimuths. Several workers[2] have performed similar experiments detecting the scattered quanta. In the experiment described a collimated beam of annihilation radiation was obtained from a Cu^{64} positron source mounted in an Al capsule at the midpoint of a $\frac{3}{8}$-in. hole through a large Pb cylinder. This radiation impinged axially upon two small thin-wall Pb cylinders. The photo-electrons ejected in directions perpendicular to the radiation beam were detected by two end window

G-M counters in coincidence and distinguished from Compton recoils and the background by an absorption method. Coincidences were recorded as each counter was rotated in azimuth. In preliminary data 56 ± 5 percent of the coincidences verify the $\sin^2(\phi_2-\phi_1)$ azimuthal dependence expected for cross polarization of the two quanta and for K and L_I photoelectron ejection. This corresponds to the ejection of some 75 percent of the electrons from the K and L_I levels.

[1] M. H. L. Pryce and J. C. Ward, Nature **160**, 435 (1947).
[2] C. S. Wu and I. Shaknov, Phys. Rev. **77**, 136 (1950), previous results are reviewed here.

Q12. Pair Production by Electrons.* MARSHALL R. CLELAND, WILFRED R. KONNEKER, AND A. L. HUGHES.—The creation of positrons by collisions of energetic electrons with nuclei has been treated by Bhabha[1] and others. Previous attempts to verify this theory experimentally have not agreed. Cloud-chamber work[2] has indicated 10^{-2} to 10^{-3} positrons per incident electron. A search for $\gamma-\gamma$-coincidences using Geiger counters[3] has yielded negative results, indicating less than 10^{-4} positrons per electron. A $\gamma-\gamma$-method has been used in this research using anthracene scintillation counters and a short resolving time coincidence circuit. A definite peak of coincidences has been observed at the 180° position. The peak has the same shape as thst produced by Cu^{61} positrons in the same geometry. A source of one millicurie of P^{32} obtained from Oak Ridge was placed inside absorbers sufficiently thick to stop all the electrons. The coincidence rate for lead absorber was 5 times the rate for aluminum absorber. In our geometry this is consistent with the Z^2 dependence of the cross section predicted by Bhabha.

* Assisted by the joint program of the ONR and AEC.
[1] Bhabha, Proc. Roy. Soc. **152**, 559 (1935).
[2] Skobelyn U. Stepanowa, J. de phys. et read. **6**, 1 (1935).
[3] Bradt, Helv. Phys. Acta **XVII**, 59 (1944).

FRIDAY AFTERNOON AT 2:15

National Bureau of Standards

East Building Lecture Room

(H. L. DRYDEN presiding)

Fluid Dynamics and Ultrasonics

R1. Incompressible, Ideal, Subsonic Flow Past an Infinite Cone. KEEVE M. SIEGEL,* *University of Michigan.*—The streamfunction for flow around a cone is derived. This is compared with the corresponding streamfunction for a wedge. A comparison is then made between pressure distributions around an infinite cone and an infinite wedge.

* USAF Contract.

R2. Vorticity Averages. C. TRUESDELL, *Naval Research Laboratory.*—Recent studies of turbulent fluid motions have drawn attention to the transfer of vorticity. The present study, eschewing conjectures regarding turbulence, proves as exact consequences of the kinematical equations the vanishing or the conservation of certain types of vorticity averages in the continuous motion of any medium whatever. The conditions for the validity of the results are satisfied by a motion within finite boundaries to which the material adheres without slipping, or by a motion vanishing at ∞ to a sufficiently high order, but are never satisfied by a plane motion. These results may offer some encouragement to those who criticise plane models of turbulence, for they show an instance where three-dimensional motions are simpler in their average properties than are plane motions.

R3. Flow of a Gas Characterized by the Beattie-Bridgeman Equation of State and Variable Specific Heats. Part II. Shock Waves.* J. C. CROWN, *Naval Ordnance Laboratory.*—The aerothermodynamic relations across both normal and oblique shock waves have been re-derived using the Beattie-Bridgeman equation of state in place of the perfect-gas law and allowing for the component of specific heat due to the vibrational mode of freedom (for polyatomic molecules). Significant deviations from the classical solution were indicated by the calculations.

* Sponsored by the ONR.

R4. Investigation of the Efficiency of a Simple Diffuser for Supersonic Wind Tunnels.* J. L. DIGGINS, *Naval Ordnance Laboratory.*—Some results are presented from the first tests in a program to determine the most efficient diffuser configuration for use in a supersonic wind tunnel. Sufficient data have been obtained at $M=2.48$ and $M=2.83$ to make possible the design of a simple yet very efficient diffuser to be used at these Mach numbers in a supersonic wind tunnel with a square cross section. A plot of pressure recovery *versus* diffuser throat location reveals that the most efficient location, at the two above Mach numbers, is 42 percent of the diffuser length from the beginning of the diffuser. This corresponds to 6.7 diameters from the nozzle exit, considering a diameter to be one side of the square which forms the nozzle exit. These values are valid for the 18×18 cm wind tunnel with a closed jet. It is further shown that the use of a half-open jet has practically no influence on the pressure recovery in this diffuser. Other curves are presented which show the optimum starting and operational throat openings and the starting and operational pressure ratios required for the whole tunnel system.

* Sponsored by the ONR.

R5. Statistical Analysis of Turbulence Data With Computing Machines.* F. N. FRENKIEL, *Naval Ordnance Laboratory.*—Turbulence recording measured with a hot wire have been analyzed using IBM machines. Various statistical characteristics of the turbulence are obtained including second- and third-order correlation coefficients, microscale of turbulence, frequency distribution of turbulent velocities, etc. The possibilities of this method of analysis are discussed.

* Sponsored by the ONR.

R6. A Solution of Lagrange's Problem of Interior Ballistics by Means of its Characteristic Lines.* W. HEYBEY, *Naval Ordnance Laboratory.*—The one-dimensional non-steady. motion set up in a highly compressed gas when it accelerates a piston in a cylinder represents a problem of long standing. The first rigorous and rather complete solution was given in 1922 by A. E. H. Love. His analysis, however, is restricted to

specific values of γ; it is intricate, and requires cumbersome computations of power series coefficients in the later stages where several expansion waves intermingle. The solving process becomes more lucid and considerably shorter when the characteristic net of the problem is developed which pictures quite naturally the interactions of the various waves and does not call for Love's separate treatment following each reflection at breech and piston. Also, any value of the ratio of the specific heats may be used. The integration is performed stepwise. Agreement was excellent with a numerical computation after Love's method.

* Sponsored by the ONR.

R7. An Electronic Method for Determining Gas Liquefaction in Shock Tubes by Light Scattering. G. A. LUNDQUIST, *Naval Ordnance Laboratory.*—One of the serious problems in the operation of hypersonic wind tunnels is the possible liquefaction of components of air at high Mach numbers. The thermodynamic conditions under which this condensation may occur in wind tunnels can be duplicated in the shock tube in the cold air behind the contact surface. The exact time and place in the shock tube at which the desired conditions exist can be determined theoretically and experimentally. By using a suitable observation point also the transit time of a gas through a hypersonic wind tunnel can be duplicated. The condensation can be detected by Rayleigh light scattering on droplets. The amount of light scattered at right angles to a collimated light beam is measured with a photo-multiplier tube and oscilloscope. The above method has already been used at the Naval Ordnance Laboratory and proven successful for the detection of water vapor condensation in the shock tube. Experiments are now being carried out on liquefaction of components of air in regions of extremely low air temperatures.

R8. On Nearly Glancing Reflection of Weak Shocks.* A. H. VAN TUYL, *Naval Ordnance Laboratory.*—When a plane shock wave moving at right angles to a plane wall strikes slightly concave corner (the edge of the corner being parallel to the shock wave), a triple shock configuration results. We assume that the shock moves in a perfect gas which is initially at rest. V. Bargmann (National Defense Research Committee AMP Report 108.2R, March 1945) has studied the flow for a sufficiently flat corner and a sufficiently weak initial shock wave. The angle of the corner will be denoted by $\pi-\epsilon$, and the Mach number behind the original shock in the reference system in which it is stationary by σ. If terms of the orders of ϵ and $\epsilon(1-\sigma)$ are retained while neglecting those of the orders of ϵ^2 and $\epsilon(1-\sigma)^2$, Bergmann showed that the flow is irrotational. Assuming that the flow is similar at all times after impact of the shock wave on the corner, the potential in the coordinates y_1, y_2 in which the flow is steady is $\Psi=\Psi_0+\Omega(y_1, y_2, \sigma)\epsilon$, where $\Omega(y_1, y_2, \sigma)$ is given in terms of elementary functions. These results have been extended to show that if terms of the orders of ϵ, $\epsilon(1-\sigma)$, and ϵ^2 are retained while those of the orders of ϵ^3, $\epsilon^2(1-\sigma)$, and $\epsilon(1-\sigma)^2$ are neglected, the flow is irrotational.

* Sponsored by the ONR.

R9. I. Kerr Cell Photography of High Speed Phenomena—Detonation and Shock Phenomena.* R. HEINE-GELDERN, E. M. PUGH, AND S. FONER, *Carnegie Institute of Technology.*—By synchronizing a Kerr cell camera with an exploding wire light source of peak intensity 3 to 5×10^8 candle power, a wide variety of non-luminous high speed phenomena can be photographed, using exposure times of approximately one microsecond. Photographs are presented showing explosive charges in the process of detonation, as well as certain interference phenomena produced by the simultaneous detonation of two charges. The technique has also been used to obtain photographs of phenomena not heretofore observed directly, such as the behavior of shock waves in transparent solids. Fairly direct observations can also be made on shock waves in non-transparent solids, such as metals, by submerging them in water; the passage of the shock wave through the metal gives rise to a shock wave in the surrounding water which in turn can be photographed. The velocity of propagation of the shock wave (and of cracking, if present) can be estimated in all cases. Thus it was found that, given a sufficiently intense shock, glass could propagate cracks at the velocity of the shock wave, which exceeds 6000 m/sec.

* Work performed under contract with the Office of the Chief of Ordnance.

R10. II. Kerr Cell Photography of High Speed Phenomena—Metal Jet Charges.* E. M. PUGH, R. HEINE-GELDERN, AND E. C. MUTSCHLER, *Carnegie Institute of Technology.*—The metal jets from high explosive charges with lined conical cavities have been successfully photographed traveling at very high speeds through air. Previous attempts to photograph these jets with visible light were unsuccessful because they are accompanied by an opaque shroud of luminous particles. To produce sharp jet silhouettes a background must have sufficient brilliance to penetrate this shroud and the camera shutter must expose less than a microsecond. The shroud can be eliminated by using liners with perfect conical apexes. Since these jets travel at speeds comparable to speeds of meteors, photographs of tips of jets passing through air furnish very clear pictures of meteoric phenomena. Photographs show that jet tips have color temperatures well above that of the background screen (lighted by an exploding wire). Evaporation of metal vapor from tip surfaces is clearly seen. Photographs are also presented which show jets penetrating water, Plexiglas, and glass as well as jets perforating steel plates.

* Work performed under contract with the Office of the Chief of Ordnance.

R11. III. Kerr Cell Photography of High Speed Phenomena—Instrumentation.* S. FONER, E. M. PUGH, R. HEINE-GELDERN, AND E. C. MUTSCHLER, *Carnegie Institute of Technology.*—The photography of non-luminous high speed phenomena (10^3 to 10^4 m/sec.) requires a rapid shutter (10^{-6} sec. or less) and an intense light source. This is accomplished by using a Kerr cell shutter synchronized electrically with the phenomenon and an electrically "exploded" wire light source, which has a peak intensity of approximately 5×10^8 candle power. In spite of this high intensity, very fast film must be used. To minimize the graininess, a large image size on the negative is desirable. This necessitates the use of a large aperture (f/2.5), long focal length (7 in.) lens which in turn requires a Kerr cell of correspondingly large aperture, operated at a high voltage (25 kv). Practical designs of large Kerr Cells, characteristics of exploding wires and the associated equipment and techniques are discussed in this paper.

* Work performed under contract with the Office of the Chief of Ordnance.

R12. Ultrasonic Absorption in Glycerol. T. A. LITOVITZ, *Catholic University of America* (Introduced by K. F. Herzfeld).—Using pulse techniques developed during the war the US absorption of glycerol is being studied in the temperature range of from plus 40°C to minus 25°C at the frequency 30.5 Mc. Tentative findings indicate the value of absorption in glycerol is 2 to 3 times the classical value. The temperature coefficient of absorption seems to be the same as the temperature coefficient of viscosity. At temperatures below −5°C the absorption reaches a peak and falls to values below even the classical value. This behavior at the lower temperatures indicates a relaxation time effect, as proposed by Eyring and Frenkel, associated with the viscosity as the liquid becomes "glasslike." The excess absorption appears to be a compressional viscosity effect such as found in water.

R13. Relative Velocities of Ultrasonic Waves in Liquids by Spark Shadow Photography.* CAVID ENER,† *Catholic University of America.*—Ultrasonic plane progressive waves of the same frequency are generated in a double optical cell containing two liquids. A shadowgraph of the two wave systems is taken by using a spark of the order of 10^{-7} sec. duration.[1] From such spark pictures the wave-lengths can be measured with a micrometer microscope, and the velocities are of course in direct proportion to wave-length. Distilled water is used as a reference liquid. The method has been checked by comparison of measurements of ultrasonic velocity in dextrose solutions with those of C. R. Randall[2] by the ultrasonic interferometer, and a good agreement is found.

* Assisted by contract with the ONR.
† From the Department of Experimental Physics, The University of Istanbul, Turkey.
[1] Hubbard, Larkin, and Zartman, J. Opt. Soc. Am. **37**, 832 (1947).
[2] C. R. Randall, Tech. Pap. Bur. Stand. **8**, 79 (1932).

R14. A Barium Titanate Coaxial Cable for the Production of a Short Duration Spark.* J. A. FITZPATRICK AND W. J. THALER, *Catholic University of America.*—A coaxial cable of barium titanate, having a dielectric constant of 1575,[1] has been used to make spark photographs of progressive ultrasonics waves in water at as high a frequency as seven megacycles per second. This cable has an over-all length of 16.5 centimeters and total distributed capacity of 0.02 microfarads thus permitting much higher energies to be used resulting in a more intense light source than has been previously employed.[2,3]

* Supported by ONR.
[1] B. H. Marks, Electronics (August 1948).
[2] J. W. Beams *et al.*, J. Opt. Soc. Am. **37**, 868 (1947).
[3] Hubbard, Larkin, and Zartman, J. Opt. Soc. Am. **37**, 832 (1947).

R15. The Maximum Pressure for Cavitation in Biological Suspensions.* EUGENE ACKERMAN, *University of Pennsylvania.*—Sonic destruction of biological cells occurs only in the presence of cavitation. Sonic fields for the experiments described here were generated by a magnetically driven, steel diaphragm which formed the bottom of a cup containing the aquaeous suspension being treated. The breakdown rate for most organisms becomes so small at intensities at which cavitation barely occurs, that a sharp pressure limit for cavitation cannot be found. Using the very sensitive G's strain of Paramecium aurelia, and also, using the optimum breakdown frequency of P candatum, a minimum effective intensity was found. This is estimated to be about $\frac{1}{3}$-atmospheres pressure amplitude. These cavities do not grow to macroscopic bubbles until the system becomes sufficiently non-linear at plate velocity amplitudes three times the minimum necessary for cavitation, i.e., until the intensities in the suspension reach about 0.3 watts/cm^2. The cavities must be filled with dissolved gases and are probably initiated at the nuclei on the surfaces of the biological cells.

* Work supported by a grant from the Raytheon Manufacturing Company.

FRIDAY AFTERNOON AT 2:15

National Academy

(R. M. BOWIE presiding)

Discharges in Gases; Electron Emission

S1. Investigation of a Low Pressure Mercury Arc.* ROBERT M. HOWE, *M.I.T.* (Introduced by W. B. Nottingham).—The electron energy distributions in the plasma of a low pressure mercury arc have been obtained using the Langmuir-probe method of analysis. The electron energy distribution curves exhibit a double slope when plotted on a log scale, indicating a non-Maxwellian distribution characterized by a depletion of fast electrons. It is believed that this depletion is caused by inelastic collisions of high energy electrons with the walls of the tube, since a close correlation between wall potential and the potential at which the depletion sets in is evident. The tantalum probes were surrounded closely in each case by tantalum guard rings, and experiment shows that the probe currents are independent of guard potential over a very wide range.

* Supported in part by the Signal Corps, ONR, and the Air Force.

S2. Anode Phenomena in High Current Arcs. C. J. GALLAGHER, *General Electric Research Laboratory.*—The power dissipated at the anode of a high current d.c. arc (50–200 amp.) has been measured by a water-cooling method for arcs in He, A, and N_2 at atmospheric pressure. The measurements were made in a partially enclosed system with gas flowing at a very low rate. The arc burned vertically with the anode at the bottom. The power at the anode ranged from 50 to 90 percent of the total power into the arc, depending on the length of the arc, the kind of gas, and the shape of the anode. As the arc length increased, the ratio of anode power to total power decreased somewhat, although both quantities increased. The heating at the anode is due to electrons accelerated by the anode drop, which give up kinetic energy and also heat of condensation. There is also some heating due to high temperature gas near the surface, plus excited atoms or dissociated molecules returning to the ground state at the surface and radiation incident from the column. There is some cooling by radiation and evaporation of anode material. The importance of these factors as they affect the increase in anode heating with increased length will be discussed.

S3. Current Fluctuations in a D.C. Gas Discharge Plasma. P. PARZEN AND L. GOLDSTEIN, *Federal Telecommunication Laboratories, Inc.*—Radiofrequency energy produced in d.c. gas discharge plasmas, in different gases, has been measured by one of us.[1] Mumford[2] has recently indicated the use of such tubes as noise standards in the microwave region. This noise power may be accounted for by a study of the electron current fluctuations in a gas discharge plasma. In general, the electron current fluctuations can be divided into two parts. One depends upon the electron temperature and the other upon the d.c. current. Expressions will be given for the spectrum of the current $I(t)$ from which it follows that the available noise power per unit frequency band is kT_e for the case of Mumford. T_e is electron temperature. For the case where the axis of the gas tube is parallel to the E vector of the wave guide, the available noise power is:

$$P=\left(kT_e+\frac{P_0}{NZ}\left[2+\frac{Z^2-4\pi^2f^2}{Z^2+4\pi^2f^2}\right]\right)df,$$

P_0 = d.c. power dissipated in plasma, N = total number of electrons in plasma, Z = collisional frequency, f = frequency of observation.

[1] L. Goldstein and N. Cohen, Phys. Rev. 73, 83 (1948).
[2] W. W. Mumford, B.S.T.J. 28, No. 4, 608 (October, 1949).

S4. Magnetically Controlled Ambipolar Diffusion. O. T. FUNDINGSLAND AND GEORGE E. AUSTIN.—Low pressure studies of volume deionization in decaying plasmas are obscured by excessive diffusion losses. The use of a toroidal-shaped tube with a co-annular magnetic field is proposed as a means for retarding diffusion to the container walls. The effectiveness of this control has been estimated by analyzing the simpler problem of a long circular cylinder with a uniform coaxial magnetic field, in which ambipolar flow to the walls is described by a single coefficient. An expression for the ambipolar diffusion coefficient as a function of energy, magnetic field B, and pressure p is derived by considering the average motion of electrons and ions in a quasi-static plasma. At high B/p it approaches the coefficient for free electron diffusion in a magnetic field, as B/p approaches zero it reduces to twice the free diffusion coefficient for positive ions, and when B is constant there is a pressure at which it has a maximum value. At 1 micron and 1000 gauss ambipolar diffusion in atmospheric gases is reduced by about 10^7 and is small compared to expected recombination. Determination of recombination coefficients by microwave techniques originating at M.I.T. will be attempted at low pressures, utilizing a coaxial cylindrical cavity with a co-annular magnetic field.

S5. The Role of Plasma Oscillations in the Description of Electron Interactions. DAVID PINES AND DAVID BOHM, *Princeton University.*—Because of the long range of the Coulomb force, the usual one-particle solutions are, for many purposes, a poor description of the interactions in a collection of electrons. As a first step in the development of a new description, we investigate classically the electron interactions in a plasma, and show that the transition from a single-particle to a collective description of the electron motion in terms of plasma oscillations can be obtained by a suitable series of canonical transformations. The complete Hamiltonian for a collection of interacting charges is re-expressed as a sum of three terms. One involves the collective field coordinates, which act like waves in an enclosure, and which express the degree of excitation of plasma oscillations. The other terms correspond to the kinetic energy of free electrons, and to the residual interparticle forces, which are found to be approximately screened Coulomb forces of very short range. This result shows that the effective collision cross-section between electrons in a dense assembly is much less than that calculated on the basis of the individual-particle approximation. A quantum-mechanical theory of plasma oscillations is now under investigation, and applications to the interactions between electrons in a metal, and to superconductivity, will be discussed.

S6. Electron Removal in Helium Afterglows.* B. T. MCCLURE, R. A. JOHNSON, AND R. B. HOLT, *Harvard University.*—Observations of the electron density, visible and near ultraviolet light intensity, and spectrum associated with a 3000-mc/sec. pulsed electrodeless discharge have been made. The techniques employed to obtain this data at various times relative to the discharge and results obtained on helium and other rare gases have been described previously.[1] Our electron density data indicated recombination-type electron removal with a constant $\alpha = 1.5 \times 10^{-8}$ cm³/ion sec., in reasonably good agreement with previous data. During the discharge, the spectrum of atomic helium predominates. In the afterglow the band spectrum of He_2 predominates. The total energy radiated in the wave-length range 2300A to 8000A is estimated as 0.5 ev per electron removed. A maximum in the light intensity occurs a few hundred microseconds into the afterglow. The following mechanism is quantitatively consistent with all of our data: He^+ forms He_2^+ by undergoing a triple collision with two neutral atoms, after which the molecular helium ions combine with electrons.

* This work was supported by the ONR.
[1] M. A. Biondi and S. C. Brown, Phys. Rev. 76, 1697 (1949), and Holt, Richardson, Howland, and McClure, Phys. Rev. 77, 239 (1950).

S7. Formative Time Lags of Spark Breakdown in Oxygen.* G. A. KACHICKAS AND L. H. FISHER, *New York University.*—Measurements of formative time lags of spark breakdown in uniform fields in air[1] are being extended to oxygen. Time lags have been measured as a function of percent overvoltage (O.V.) and pressure for a plate separation of 1 cm. In air, the time lags are independent of pressure over a wide pressure range, and vary from about 100 μsec. at 0.01 percent O.V. to about 1 μsec. at 2 percent O.V. In oxygen, however, the time lag variation with pressure is very pronounced. The variation of time lags with percent O.V. is also quite different. For a given percent O.V., the formative time lags in oxygen are much longer than in air. For example, in oxygen near atmospheric pressure, the time lags vary from approximately 100 μsec. at 1 percent O.V. to about 1 μsec. at 2.5 percent O.V. Thus at 1 percent O.V., the lags are 100 times longer in oxygen than in air. (The present apparatus does not permit measurement of times greater than 100 μsec.) It is not yet clear whether a mechanism in addition to space-charge distortion of the field by positive ions is necessary to explain the results.

* Supported by the ONR and the Research Corporation.
[1] L. H Fisher and B. Bederson, Phys. Rev. 75, 1324, 1615 (1949); Bulletin, Am. Phys. Soc., 1950 Annual Meeting.

S8. Electrical Oscillations in Spark Discharges.* HARRY S. ROBERTSON AND G. H. DIEKE, *University of Miami and The Johns Hopkins University.*—Several observers have reported the presence of unidentified oscillations in the current of a spark discharge in an LC circuit. The expected discharge current should be in the form of a damped sinusoid of frequency approximately $1/2\pi(LC)^{\frac{1}{2}}$. Two other oscillations have been isolated. One of these, called the parasitic, is due to a secondary resonance in the circuit formed by the lead and other stray inductances, together with the distributed capacity of the inductor. The parasitic oscillation is excited, along with the fundamental component of the current, at the initial breakdown. It is probably the component responsible for most of the radio interference. The second stray oscillation, tentatively called the spark oscillation, always originates during the transition from the glow form of the discharge to the so-called cold-cathode arc. The nature of the spark oscillations is not understood, but there is evidence that the oscillations originate in the gap and are not related to the external circuit.

* This work was supported through an ONR contract with The Johns Hopkins University.

S9. Production of High Current Electron Pulses by a Resonant Cavity Accelerator. G. W. CLARK AND L. B. SNODDY, *University of Virginia.*—A doubly reentrant cylindrical cavity operating at approximately 400 Mc is used in conjunction with a pulsed electron source to produce a high current beam of less than 10^{-7}-sec. duration. The cavity is driven by a 7 C 22 pulse-operated twin triode. Near the end of the 5 μsec. driving pulse a metal vapour arc is formed on the surface of one of the cavity electrodes by a high current pulse of short duration. Electrons are drawn from the arc plasma and accelerated by the cavity field across the space between the electrodes. With the present arrangement 2×10^{12} electrons with energies greater than 40 kev can be obtained in a single pulse lasting less than 10^{-7} sec. This current is about ten times that measured in previous experiments.[1]

[1] L. B. Snoddy and J. W. Beams, Phys. Rev. 75, 1324 (1949).

S10. Crystallographic Variations in Field Emission from Single Tungsten Crystals.* MICHAEL K. WILKINSON. *M.I.T.* (Introduced by W. B. Nottingham).—By means of a spherical projection tube with a point filament etched electrolytically from tungsten wire and mounted on a hairpin filament for heating, a field emission pattern is observed showing the relative emission from a tungsten crystal along the various crystallographic directions. With the latest techniques in high vacuum procedure, a vacuum is reached which is sufficiently good that the emission pattern of clean tungsten is stable for periods of about an hour. The photometry of the pattern produced on the spherical fluorescent screen yields data that give the relative emission currents as the electric field at the filament is varied. These data are then interpreted according to the theoretical field emission equation derived by Fowler and Nordheim. Data now available indicate that the dark areas of the emission pattern are crystallographic directions for which the slope of the plotted line is higher than that determined by direct electrical measurement for the point as a whole. The bright areas represent crystallographic directions for which the slope is lower than the average.

* Supported in part by the Signal Corps, ONR, and the Air Force.

S11. Deterioration of Oxide-Coated Cathodes Under Low Duty-Factor Operation.* J. F. WAYMOUTH, JR., *M.I.T.* (Introduced by W. B. Nottingham).—A study has been made of the effect of emission current duty-factor on oxide cathode life. End of life is identified either by failure to yield an arbitrary specified emission or by the presence of an excessive potential drop across the coating for a given pulsed emission. For cathodes coated on nickel cores containing relatively high percentages of impurities (Si, Mn, Fe, etc.) mounted in diodes in which especial care had been taken to eliminate spurious impurities from the remainder of the structure, zero duty-factor operation is found to cause a high incidence of the development of cathode interface resistance. The interface resistance is found to be consistent with the hypothesis of an insulating layer several thousand atom diameters in thickness located at the interface between coating and core.

* Supported in part by the Signal Corps, the ONR, and the Air Force.

S12. Effect of Patch Fields on Schottky Deviations.* E. A. COOMES, R. J. MUNICK, AND W. B. LA BERGE, *University of Notre Dame.*—Schottky deviations[1] have been observed for clean tantalum wires for fields from 50 to 300,000 volts/cm, and in a temperature range from 1100° to 1700°K. The slope of the Schottky plots agreed with measured temperatures at low and high fields, but had an anomalous value at intermediate fields, in accordance with patch theory.[2] The breaks in slope indicate a patch size in good agreement with microphotographic grain growth observations on tantalum ribbons.[3] Breaks in slope show that patches grow in size when the wire is heat treated. Using the Schottky slopes determined experimentally, computed deviations from the Schottky line are continuous in phase and amplitude over the entire range of measurement. The observed maxima and minima are in fair agreement with the Guth-Mullin theory,[4] and there are no indications that patch fields disturb the effect at low applied fields, even down to where space charge might become important.

* This work sponsored by U. S. Navy Bureau of Ships.
[1] R. L. E. Seifert and T. E. Phipps, Phys. Rev. **56**, 652 (1939).
[2] J. A. Becker, Rev. Mod. Phys. **7**, 95 (1935).
[3] B. A. Mrowca, J. App. Phys. **14**, 684 (1943).
[4] E. Guth and C. J. Mullin, Phys. Rev. **59**, 575 (1941).

S13. Low Frequency Fluctuations in the Tungsten-Lamp-Photo-Cell System. BRITTON CHANCE, *University of Pennsylvania.*—In the course of development of methods for detecting very small changes of optical density ($\log Io/I < 10^{-3}$) of enzyme solutions occurring in a time range 10 msec. to 10 min., several attempts have been made to achieve a signal to noise ratio limited only by the shot noise of the photo-current.[1] In the system, voltage-regulated tungsten lamp, double-grating monochromator, and differential caesium-antimony photo-cells, the light intensity fluctuations due to lamp voltage variations are reduced to the equivalent of 2×10^{-6} in the photo-current while the actual amplitude of low frequency fluctuations ($\sim$0.1 c.p.s.) corresponds to 2×10^{-5}. Shot noise would contribute 5×10^{-6}. This fluctuation is independent of the wave-length of light illuminating the photo-tube (4000 to 5600A), independent of the photo-cell anode voltage (5–150 v), independent of the total photo-current (0.05–0.25 μa), but decreases with decreasing lamp voltage or temperature. Thus this excess fluctuation does not appear to be attributable to the lamp regulation circuit or to the photo-cells and may be due to a property of the tungsten filament of the lamp.

[1] B. Chance, Rev. Sci. Inst. **18**, 601 (1947).

S14. New Type of High Speed Coincidence Circuit.* Z. BAY, *George Washington University* (Introduced by R. O. Wales).—A new principle for a high resolving coincidence device was tried and found successful. (1) We compare some characteristic quantity Q_A of the pulses measured in channel A with the same kind of quantity Q_{AB} measured simultaneously between the channels A and B. With a pulse in A only, Q_A and Q_{AB} are equal, while in the case of coincidence $Q_A - Q_{AB} \neq 0$. (2) With a pulse in B only, we can make Q_{AB} equal zero and thus $Q_A - Q_{AB} = 0$ by applying a rectifier characteristic to the measurement of Q_{AB}. In the actual performance we used crystal diodes for the measurements, Q_A and Q_{AB} being here the charges going through the diodes and collected in separate condensers. For the measuring of $Q_A - Q_{AB}$ we used either a differential amplifier, or a self-subtracting circuit developed for this purpose and an ordinary pulse amplifier. The circuit built by us will respond to unequal pulses and uses no vacuum tubes or voltage supplies in the coincidence device, which is small in size and is stable. Using electron multiplier pulses we have been able to get resolving times $<10^{-9}$ sec. and to detect and measure time delays $\sim10^{-10}$ sec.

* Supported by the ONR.

FRIDAY EVENING AT 7:00

Grand Ballroom, Mayflower Hotel

(I. I. RABI presiding)

Banquet of the American Physical Society

After-dinner speech by W. V. HOUSTON, *Rice Institute.*

SATURDAY MORNING AT 10:00

Lisner Auditorium

(I. I. RABI presiding)

Invited Papers

T1. Recent Developments of Nuclear Induction. FELIX BLOCH, *Stanford University.* (50 min.)

11:00 A.M.

T2. Galactic Radio Waves. GROTE REBER, *National Bureau of Standards.* (30 min.)

11:40 A.M.

T3. How to Write Scientific Papers. D. H. MENZEL, *Harvard University.* (45 min.)

SATURDAY MORNING AT 10:00

National Bureau of Standards

East Building Lecture Room

(R. S. MULLIKEN presiding)

Molecular Spectroscopy in the Infra-Red Region; Molecular Interactions

U1. The Spectrum of Water Vapor in the Region of 2.7μ. W. S. BENEDICT AND E. K. PLYLER, *National Bureau of Standards.*—Using a 15,000-line grating and a lead sulfide photo-conductive cell, spectra of water vapor between 2.4 and 2.9μ have been obtained with resolution considerably better than previously reported (H. H. Nielsen, Phys. Rev. 62, 422 (1942)). The spectral slit width varied between 0.08 and 0.2 cm^{-1} and lines as close as 0.2 cm^{-1} are partially resolved. The bands of CO_2 in this region also appear. A quite complete rotational analysis of the results has been possible, which does not confirm earlier work in all details. Practically all the intense lines belong either to the ν_3 fundamental, of which energy levels have been located up to $J=10$, or to CO_2; the ν_1 fundamental has also been found, with intensity relative to ν_3 about 1:15, and with ν_0(vac) at 3656.2 ± 0.4 cm^{-1}. There are numerous examples of rotational perturbations between ν_1 and ν_3. If the strongest line of ν_3 is assigned a calculated relative intensity of 100, all predicted lines of intensity greater than 1 have been found.

U2. The Effect of Aging and of Heat Treatment on the Infra-Red and Ultraviolet Spectra of Urea.* RUTH C. SHEA AND GLADYS A. ANSLOW, *Smith College.*—Infra-red spectra from 2.5 to 7.5μ were obtained with a Perkin-Elmer recording spectrophotometer, employing CaF optics and ultraviolet spectra with a Beckmann quartz spectrophotometer and Lyman vacuum spectrograph. Crystals were deposited from methanol solutions on CaF plates in a vacuum desiccator or suspended in Nujol. Water solutions were heat-treated as previsously described.[1] In the 3μ region the intensities of the two N−H stretching vibration bands for unassociated bonds exceed those for associated bonds in freshly deposited specimens; during a three day period the intensities of the associated bands increase, after which a stable state appears established with the 3216 cm^{-1} association stronger than the 3160 cm^{-1} association band. The ultraviolet spectra show similar variance with degree and type of association. Solutions of freshly purified crystals give bands indicating more unassociated amide groups than do solutions from aged crystals and indicate associated water. End absorption characteristic of dimers is obtained from rapidly cooled solutions, and of polymers from slowly cooled specimens. Comparison is made with the ultraviolet spectra of acetamide.

* Supported by the ONR.

[1] G. A. Anslow and R. C. Shea, Phys. Rev. **75**, 1318 (1949).

U3. The Origin of the Weak Absorption in the Near Ultraviolet Spectra of Hydrogen-Bridged Amides and Alcohols.* GLADYS A. ANSLOW, *Smith College.*—In previous discussions the end absorption in the ultraviolet spectra of hydrogen-bridged molecules has been attributed to the rupture of the bond and bridge, following electronic excitation. At lower photon energies weaker bands appear, some with structure, probably resulting from rupture of the bridge with excitation of the bond to the lower vibrational energy states of the excited level. In some instances negative absorption coefficients were obtained in this region, attributable to reassociation. Bands with onsets near 35000 cm^{-1} and 38000 cm^{-1} in cyclic amides, containing water of crystallization, and in alcohols may result either from the (0, 1) and (0, 2) electronic-vibrational transitions or from ground state vibrational dissociation of unassociated or associated hydroxyls, respectively. Since the 35000 cm^{-1} band appears in the water-bound amides and in those alcohols, for which boiling point and infra-red data indicate low polymerization, and the 38000 cm^{-1} band predominates in highly polymerized alcohols, and since transition probabilities for $G''(0)\rightarrow G''(v_{max})$ for the highly perturbed energy states of such molecules must be large, evidence supports the second hypothesis.

* Supported by the ONR.

[1] See paper No. U2; also G. A. Anslow *et al.*, J. Chem. Phys. **17**, 436 (1949); Phys. Rev. **77**, 423 (1950).

U4. Raman and Infra-Red Spectra of Pentaborane.* W. J. TAYLOR, C. W. BECKETT, J. Y. TUNG, R. B. HOLDEN, AND H. L. JOHNSTON, *Ohio State University.*—The Raman spectrum of liquid pentaborane (B_5H_9), and the infra-red spectrum of the gas from 3 to 25 microns, have been obtained. The Raman lines observed are: 470, vvw; 566, 596, 616, w, dp; 700, 738, 782, m, dp; 793, 803, s, p; 884, w, dp; 982, vs, p; 999, s, p;

1120, m, p; 1170, 1193, vw, p; 1350, 1387, 1440, vw; 1740–1840, w, dp, diffuse band; 1840, m, p; 1870–2300, ~10 vw lines; 2077, 2152, w, p; 2600 cm^{-1}, vs, dp.[1] The principal infra-red absorption bands observed are: 570, m; 605, 619, 628, vs; 702, vw; 798, 807, m; 815, 820, w; ~900, vs, broad; 1035, 1045, m; 1125, w; 1143, 1187, 1210, 1230, vw; ~1415, vs, broad; 1500, w; 1620, m; 1800, s; 2100, 2250, 2460, vw; ~2600, vs; 2700–3300 cm^{-1}, 6 vw bands.[1,2] The interpretation of the spectral data is discussed for two models: the pyramidal structure (C_{4v} or C_{2v}), and the cyclopentadiene-like bridge structure (C_{2v}) suggested by Pitzer. The spectral data are not entirely conclusive; however, the pyramidal structure is strongly supported by the calorimetric entropy obtained in this laboratory, and is also more consistent with the published electron diffraction data than the bridge model.

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

[1] v = very; w = weak; m = medium; s = strong; p = polarized; dp = depolarized.

[2] The bands in the NaCl region are confirmed by an unpublished spectrogram from the General Electric Company.

U5. Absorption Spectra of the Xylene Vapors in the Near Ultraviolet.* C. D. Cooper and H. Sponer, *Duke University.*—The xylenes were studied using a 3-meter grating spectrograph and quartz absorption cells of different lengths. Discrete absorption occurs in the region between 2850 and 2375A for all three compounds. The *ortho*-spectrum is the sharpest of the three and the richest in bands while the *meta*-spectrum has the least number of bands and the most diffuse appearance. Rough intensity measurements indicate that the *para*-spectrum is about three times as strong as the meta- or *ortho*-spectrum. The 0,0 bands are located for ortho at 37308 cm^{-1}, for *meta* at 36955 cm^{-1}, and for *para* at 36733 cm^{-1}. Prominent upper state frequencies which appear in progressions and combinations are for *ortho* 1195, 939, 692, and 507; for *meta* 1245, 965, and 470; and for *para* 1186, 802, 775, and 552. Many bands must be explained as resulting from v − v transitions. These v − v transitions are more plentiful in *ortho* than in the other two spectra.

* This work was supported by ONR.

U6. The Infra-Red Spectrum of Crystalline Hydrogen Sulfide. J. B. Lohman and D. F. Hornig, *Brown University.*—The infra-red absorption of crystalline hydrogen sulfide at −195°C has been examined between 800 cm^{-1} and 2800 cm^{-1}. In contrast to water, the main absorption peaks are very sharp, indicating an ordered crystalline structure. Absorption peaks at 1170 cm^{-1}, 2517 cm^{-1}, and 2540 cm^{-1} have been tentatively assigned to components (arising from crystalline coupling) of ν_2, ν_1, and ν_3 of the free molecule, respectively; weaker peaks at 1184 cm^{-1}, 2622 cm^{-1}, and 2722 cm^{-1} appear to be combinations of fundamentals with lattice vibrations. Reported x-ray studies of the hydrogen sulfide[1] crystal indicated a face-centered cubic crystal structure which implied a linear molecule. The infra-red and Raman spectra[2] of the crystal are not consistent with a crystal of higher than tetragonal symmetry, a conclusion consistent with the accepted non-linear structure of the hydrogen sulfide molecule.

[1] L. Vegard, Naturwiss. **18**, 1098 (1930).

[2] G. M. Murphy and J. E. Vance, J. Chem. Phys. **6**, 426 (1938).

U7. Remarks on the Infra-Red Spectrum of Deuteronaphthalene.* L. Corrsin, *Duke University.*—The infra-red spectrum of a newly synthesized sample of deuteronaphthalene will be compared with a spectrum of very pure ordinary naphthalene. These spectra taken in carbon tetrachloride and carbon disulfide solutions at the U. S. Bureau of Standards by Dr. E. K. Plyler and Miss Mary A. Lamb cover almost the entire region of the fundamental vibrations. Tentative assignments will be given for a number of prominent bands which were identified because of their strength, spectral region and isotope shift.

* This work was supported by the ONR.

U8. Relaxation Times for Exchange of Vibrational Energy in Gas Molecules. Wayland C. Griffith,* *Harvard University.*—The fact that the internal energy states of molecules fail to keep up with sufficiently rapid changes in their environment has important implications in some flow problems. Relaxation times for exchange of energy among the various modes of motion have been studied for seventeen gases: H_2, N_2, SO_2, CO_2, N_2O, NH_3, CH_4, C_2H_6, C_3H_8, C_4H_{10}, C_2H_4, C_4H_6, CCl_2F_2, $CHClF_2$, CH_3Cl, $CH_2{:}CHCH{:}CH_2$, and C_2H_4O. The measurements are based on a steady flow technique devised by Kantrowitz.[1] The total head in a jet read with a small pitot tube differs from the stagnation pressure in the reservoir by an amount that can be related to the relaxation time through the jet velocity and the pitot tube diameter. An accurate solution for the flow pattern involved has been found numerically using Southwell's Relaxation Method. Experimental techniques were developed which gave quite accurate and consistent results with very small scale measuring equipment. It was thus economical to expend the gas as in a blow-down wind tunnel, and gain the advantage of easily studying many gases of high purity. For gases on which sound dispersion data is also available good agreement is found between the two methods.

* Present address; Princeton University.

[1] A. Kantrowitz, J. Chem. Phys. **14**, 150 (1946).

U9. Gaseous Data of State for Hydrogen between 1 and 200 Atmos. from 20 to 300°K.[1] Herrick L. Johnston, Irving J. Bezmann, Thor Rubin, Lyle Jensen, David White, and Abraham S. Friedman, *Ohio State University.*—An apparatus, patterned after that of Bartlett[2] but similar in design to a precision vacuum calorimeter, has been developed at the Ohio State University Cryogenic Laboratory for measuring gaseous PVT data at low temperatures to an accuracy of 1 part in 10,000. Approximately 30 PV isotherms have been determined for hydrogen at temperatures of 20 to 300°K for pressures up to 200 atmos., and have been used to calculate the second and third virial coefficients. The saturated vapor pressure curve has also been determined. The Boyle Point was found to be 104.0±0.5°K, and the critical temperature and pressure 33.24°K and 12.797 atmos., respectively.

[1] This work was supported in part by the Air Materiel Command under contract with the Ohio State University Research Foundation.

[2] Bartlett, J. Am. Chem. Soc. **49**, 687 (1927).

U10. Intermolecular Force Constants for Hydrogen and for Nitrogen. David White, Abraham S. Friedman, and Herrick L. Johnston, *Ohio State University.*—The intermolecular force constants of hydrogen and of nitrogen have been determined using the potential function:

$$\epsilon_{(r)} = \epsilon_0\left[\frac{n}{n-m}\left(\frac{r_0}{r}\right)^m - \frac{m}{n-m}\left(\frac{r_0}{r}\right)^n\right],$$

where n and m equal 12 and 6, respectively. The determinations make use of our own values of the second virial coefficients, obtained recently from low pressure data of state between room temperature and the boiling points of the respective gases. The values of r_0 and $\epsilon_0 - k$ are 3.35A and 30.69 degrees for hydrogen, and 4.15A and 95.93 degrees for nitrogen.

U11. The Forces of Interaction in a Solution of Two Non-Polar Gases: Hydrogen and Nitrogen. David White, Abraham S. Friedman, and Herrick L. Johnston, *Ohio State University.*—The intermolecular force constants for a hydrogen-nitrogen solution have been evaluated from experimental second virial coefficients. It is shown that the interaction virial coefficients B_{12} and the virial coefficients for mixtures

B_{mix} can be fitted to a 6–12 Lennard-Jones potential function. The values of ϵ_{12}/k and r_{12} are -50.81_6 deg. and 3.78A, respectively. The interaction constants obtained from the values of B_{mix} at various concentrations lead to the following simple combination rules:

$$(\epsilon_0/k)_{mix}=N_1(\epsilon_0/k)_1+N_2(\epsilon_0/k)_2$$
$$(r_0)_{mix}=N_1(r_0)_1+N_2(r_0)_2.$$

Thus, the intermolecular force constants and virial coefficients can be computed for any binary gas mixture from a knowledge of the force constants of the pure gases.

U12. Intermolecular Force Constants for Helium and for Deuterium. DAVID WHITE AND HERRICK L. JOHNSTON, *Ohio State University.*—The intermolecular force constants for helium and for deuterium have been evaluated from experimentally determined second virial coefficients using a Lennard-Jones 6–12 potential function. The constants namely ϵ_0/k and r_0 obtained for helium are 7.40 degrees and 2.65A, respectively, which differ considerably from previous values evaluated from data of state, especially in the case of ϵ_0/k. Our value of ϵ_0/k indicates that the Boyle point for helium is 25.4°K instead of 20.7°K, as would be obtained from the previous constants. The constants of the Lennard-Jones 6–12 potential functions for deuterium are 33.27 degrees and 3.39A for ϵ_0/k and r_0, respectively. The latter value agrees with the r_0 obtained earlier for hydrogen, but the ϵ_0/k value is slightly higher, indicating a deeper "well" and a higher Boyle point. The second virial coefficients for deuterium were found to be considerably different from those for hydrogen, and the difference can be ascribed to quantum effects as given by Shafer[1] and by de Boer and Michels.[2]

[1] K. Shafer, Zeits. f. Physik. Chem. **B38**, 187 (1937).
[2] J. de Boer and A. Michels, Physica **5**, 945 (1938).

U13. The Second Virial Coefficients of Non-Polar Binary Gas Mixtures. DAVID WHITE, *Ohio State University.*—A method recently suggested by White, Friedman, and Johnston[1] for predicting second virial coefficients of non-polar binary mixtures has been tested on a set of seven gaseous mixtures where experimental data of reasonable accuracy were available. The method implies that B_{mix}, the second virial coefficient for the mixture, fits a 6–12 Lennard-Jones potential function with intermolecular force constants

$$(\epsilon_0/k)_{mix}=N_1(\epsilon_0/k)_1+N_2(\epsilon_0/k)_2$$

and

$$(r_0)_{mix}=N_1(r_0)_1+N_2(r_0)_2.$$

Where $(\epsilon_0/k)_1(\epsilon_0/k)_2(r_0)_1(r_0)_2$ are the intermolecular force constants of the pure components 1 and 2 obtained from a Lennard-Jones potential function, and N_1 and N_2 the mole fractions. This combination rule reproduces the experimental values very well. The combination rule used by Hirschfelder and Roseveare[2] for evaluation of the interaction virial coefficients B_{12} for binary mixtures has also been compared with the experimental data. In nearly all the cases, this rule was also found to lead to values of B_{mix} which agree well with the experimental values.

[1] White, Friedman, and Johnston, to be published.
[2] J. O. Hirschfelder and W. E. Roseveare, J. Chem. Phys. **43**, 15 (1939)

SATURDAY MORNING AT 10:00

National Academy

(M. GOLDHABER presiding)

Beta-Emitters. I

V1. Beta-Ray Spectrum of K^{40}. DAVID E. ALBURGER, *Brookhaven National Laboratory.**—A measurement of the beta-ray spectrum of K^{40} has been made using a lens spectrometer at 17 percent resolution. The source was prepared under the direction of C. P. Keim by electromagnetic enrichment at the Oak Ridge Y-12 plant. The K^{40} content is 7.13 percent. Enriched KCl was deposited by precipitation over a 4 cm^2 area on 0.5 mg/cm^2 Nylon backing. The average thickness of the source was 2.4 mg/cm^2. A maximum net counting rate of 16 per minute was observed above a background of 18 per minute. Calculated correction for resolution was made by graphical integration. The Kurie plot, corrected by the 3rd forbidden axial vector or tensor interaction factor for spin change 4, is linear from about 500 kev to the end-point at 1.38±0.03 Mev. Other forbidden transition factors have been applied to the data. α appears to give a non-linear plot but a D_2 correction is linear above 500 kev and cannot be excluded with present data. Deviations below 500 kev are thought to be due to effects of source thickness and are being investigated by comparison studies using allowed beta emitters mixed in normal KCl.

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

V2. Beta-Disintegration of Sc^{44}.* A. BRUNER** AND M. LANGER, *Indiana University.*—In an attempt to understand the unusual positron spectrum shape reported by G. P. Smith, the Sc^{44} disintegration has been reinvestigated with a 15 cm radius of curvature shaped magnetic field spectrometer. The source was prepared by bombarding an enriched sample (91.6 percent) of K^{41} with 22 Mev alpha-particles in the cyclotron. A Fermi plot of the data indicates that there are two groups of positrons with end points at 1.478±0.005 and 0.955±0.010 Mev. All parts of the distribution are found to decay with the same composite period resulting from the initial activation of both isomeric states, with the subsequent feeding of the 4.0 hr. level by the 57 hr. level. The general shape is quite different from that found by Smith. An examination of the photoelectrons ejected from a uranium radiator indicates the existence of a 1.25 Mev gamma-ray which, from its intensity, apparently is associated with at least some K-capture. Displacement of the back edges of the annihilation radiation lines suggests a gamma-ray of 0.52 Mev corresponding to the difference between the beta-end points. From the measurement of conversion electrons, the energy of the gamma-transition between the isomeric states is found to be 271.3±0.7 kev.

* Assisted by a grant from the Frederick Gardner Cottrell Fund of the Research Corporation and by the joint program of ONR and AEC.
** AEC Predoctoral Fellow.

V3. Internal Conversion Coefficients in Co^{60}. M. A. WAGGONER, M. L. MOON, AND A. ROBERTS, *State University of Iowa.*—Using a two-coil, thin lens β-spectrometer we have measured internal conversion coefficients in Co^{60}. In integrating the β-spectrum we assumed an allowed shape, as indicated by our results and previous experiments.[1] The end point was

318.7±4.0 kev. We obtained for coefficients for conversion in K, L, M shells together (unresolved): $\alpha_{1.17}=(1.733\pm0.061)\times10^{-4}$, $\alpha_{1.33}=(1.286\pm0.035)\times10^{-4}$. Theoretical values[2] of conversion coefficients for K shell for electric quadrupole radiation are: $\alpha K_{1.17}=1.545\times10^{-4}$, $\alpha K_{1.33}=1.175\times10^{-4}$. Conversion coefficients for other types of radiation differ from EQ by a factor 2 or more. Supposing $L+M$ conversion and screening corrections to be about 10 percent, we may classify both gamma-rays as EQ. Angular correlation experiments[3] show both gamma-rays to be quadrupole transitions with $J=4\rightarrow2\rightarrow0$. Present results fix all parities as even. Quantitative comparison with internal conversion theory requires evaluation of L conversion and screening corrections.

[1] Deutsch, Elliott, and Roberts, Phys. Rev. **68**, 193 (1945).
[2] Rose, Goertzel, Spinrad, Harr, and Strong, Phys. Rev. **76**, 184 (1948).
[3] Brady and Deutsch, Phys. Rev. **74**, 1541 (1948).

V4. The Disintegration of Ga^{66}.* R. D. MOFFAT AND L. M. LANGER, *Indiana University.*—The radioactivity of Ga^{66} has been studied in the 180° focussing, 40 cm radius of curvature, shaped field spectrometer. The activity was produced by $Cu^{63}(\alpha,n)Ga^{66}$ in the cyclotron. The positron distribution is found to consist of four groups having end-point energies and relative intensities as follows: 4.14 Mev, 87.0%; 1.4 Mev, 4.3%; 0.88 Mev, 6.9%; 0.40 Mev, 1.7%. In spite of the high ft value ($\sim10^8$), the highest energy group has a spectrum shape characteristic of an allowed transition. Since the transition from Ga^{66} to the ground state of Zn^{66} presumably involves *no* change of parity, one might expect that the 4.14 Mev spectrum does not go directly to the ground state. From measurements on the photo and compton electrons ejected from a radiator, gamma-rays are found with energies of 4.8, 2.75 and 1.03 Mev. The 1.03 Mev gamma is the most intense—about 300 times that of the 2.75 Mev. One can propose a reasonable level scheme for Zn^{66} only if the 1.03 Mev gamma follows the 4.14 Mev beta-transition. Since no β-γ-coincidences are found associated with the 4.14 Mev group, it must be assumed that the lifetime of the 1.03 Mev level is longer than 10^{-6} sec. Excited states of Zn^{66} lie 1.03, 3.78, 4.29 and 4.8 Mev above the ground state.

* Assisted by a grant from the Frederick Gardner Cottrell fund of the Research Corporation and by the joint program of ONR and AEC.

V5. Radiations from As^{72} and As^{71}. J. Y. MEI, ALLAN C. G. MITCHELL, AND C. M. HUDDLESTON, *Indiana University.**—Gallium was irradiated by alpha-particles and the resulting arsenic radiations studied in a magnetic lens spectrometer. When 23 Mev alpha-particles were used As^{72} (26 hours), As^{74} (17.5 days), As^{73} (90 days), and As^{71} (60 hours), the latter from $(\alpha, 2n)$ reactions, were obtained. When the bombarding energy was reduced, the radiations from As^{73} and As^{71} disappeared. The radiations from As^{72} were similar to those of Ga^{72}. The photo-electron spectrum showed a gamma-ray of 0.835 Mev, together with many weaker ones extending out to around 3 Mev. The beta-ray spectrum shows an internally converted line corresponding to a gamma-ray energy of 0.702 Mev (not seen in the photo-electron spectrum) and five beta-ray groups at 3.38, 2.486, 1.849, 0.669 and 0.255 Mev. The levels correspond closely to those obtained in Ga^{72}. As^{71} decays by K-electron capture accompanied by an internally converted gamma-ray at 0.173 Mev. Information on As^{74} and As^{73} will be given.

* Assisted by the joint program of ONR and AEC.

V6. Radiations Emitted by Sr-85.* LIN-SHENG CHENG AND J. D. KURBATOV, *Ohio State University.*—Strontium 85, produced by activation of rubidium with deuterons was separated without addition of common strontium. The radiations emitted by carrier free Strontium 85 were studied by coincidence procedure. It was found that this species disintegrating by orbital electron capture emits converted gamma-rays of ~510 kev and ~185 kev, the latter highly converted. The electron-photon coincidence measurements showed that monochromatic electrons of ~170 kev are in coincidence with x-rays and not with 510-kev photons. Also, data were obtained for the existence of several groups of monochromatic electrons of higher energy and of low abundance. No evidence was secured for the 800-kev photons previously reported as emitted by Sr-85.

* Assisted by a grant of the Alumni Development Fund of the Ohio State University.

V7. Disintegration of Ru^{103}. J. Y. MEI, C. M. HUDDLESTON, AND ALLAN C. G. MITCHELL, *Indiana University.**—Ruthenium was irradiated in the Oak Ridge pile. After a separation consisting of a distillation of RuO_4, the beta- and gamma-radiations were studied with a magnetic lens spectrograph. The photo-electrons ejected from a lead radiator showed K and L lines for a gamma-ray of energy 0.494 Mev, belonging to Ru^{103} (42 days) and a K line for a gamma-ray of 0.217 Mev belonging to Ru^{97} (2.8 days). The beta-ray spectrum of an aged source gave two groups of beta-rays with end points at 0.684 Mev (10 percent) and 0.204 Mev (90 percent). An internal conversion line corresponding to the gamma-ray at 0.494 Mev and also a conversion line at 0.035 Mev emitted from the product Rh^{103m} were found. The disintegration scheme of Ru^{103} will be discussed.

* Assisted by the joint program of ONR and AEC.

V8. Beta-Spectrographic Investigation of Ru^{103} and Rh^{103m}.* A. J. SAUR,†, P. AXEL, L. G. MANN, AND J. OVADIA, *University of Illinois.*—A double thin-lens beta-ray spectrometer was used to investigate the beta-spectrum of Ru^{103} and its daughter Rn^{103m}. In agreement with the evidence from absorption measurements,[1] two beta-spectra were found. The low energy, relatively intense spectrum has an energy of 205 kev while the less intense, high energy spectrum has an energy of 670 kev. The intensity relations are such that at least part of the low energy beta-rays lead to the 52-minute isomeric state in Rh^{103}. A conversion peak was found at 37 kev which has been interpreted as the L conversion of a 40-kev gamma-ray in Rh^{103m}. This interpretation is dictated by the absence of an electron line at about 57 kev (where one would be found if the 37-kev line were a K conversion line). The expected intensity of a line at 57 kev was estimated using the $l=4$ assignment for Rh^{103m}.[2] The interpretation is consistent with the data of Gunlock and Pool[3] who resolved the L and M conversion lines. A discussion of the gamma-rays and a decay scheme will be given.

* Supported in part by the joint program of the ONR and the AEC.
† AEC Predoctoral Fellow.
[1] C. E. Mandeville and E. Shapiro, Phys. Rev. **77**, 439 (1950).
[2] P. Axel and S. M. Dancoff, Phys. Rev. **76**, 892 (1949).
[3] H. F. Gunlock and M. L. Pool, Phys. Rev. **74**, 1264 (1948).

V9. The 282-Day Radioactivity in Silver 110.* W. C. RUTLEDGE, A. E. STODDARD, C. E. BRANYAN, J. LEBLANC, AND J. M. CORK, *University of Michigan.*—In our earlier study of the long-lived radioactivity in silver associated with mass 110, obtained by the activation of silver in the pile, a half-life of 282 days was observed. Many electron lines were present due to internal conversion. The K–L–M differences for certain of these lines were characteristic of silver indicating the emission of a gamma-ray preceding beta-emission. Four gamma-rays were reported. A subsequent investigation by Siegbahn showed these four together with six additional gamma-rays. With longer photographic exposures and more efficient emulsions, using both internal conversion and photo-electrons from lead and uranium, an enormous number of previously unobserved electron lines are now visible. In total, there appear to be about 26 gamma-rays, only one of which (115.9 kev) has K–L–M differences characteristic of silver while the

others, where observable, have differences characteristic of cadmium as expected following beta-emission from silver. With so many gamma-energies, it is possible to propose several nuclear level schemes, no one of which is unique.

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

V10. Radioactivity in Enriched Cadmium Isotopes.* J. M. CORK, W. C. RUTLEDGE, A. E. STODDARD, C. E. BRANYAN, AND J. LEBLANC, *University of Michigan.*—Isotopes of cadmium enriched in masses 108 and 114, produced by Carbide and Carbon Chemicals Division, Oak Ridge National Laboratory, were made available by the AEC and irradiated in the pile. Spectrometric and absorption studies on the different samples revealed many gamma-rays not previously observed, and allowed a positive isotopic assignment of the long-lived radioactivities. Cadmium 109, whose half-life has been reported as from 156 to 300 days, decays by K-capture to silver 109 with the subsequent emission of a highly converted gamma-ray of energy 87.5 kev, and probably another whose energy is 86.3 kev.

Cadmium 115 is isomeric with half-lives 2.4 days and a longer period reported as being from 40 to 44 days. The 2.4-day activity emits a beta-ray followed by several converted gamma-rays in indium 115, whose energies are 335.5, 343.7, 348.9, 369.3, 451.9, 559.1, and 713.1 kev. The longer-lived Cd 115 activity has a beta-upper limit of 1.53 Mev and probably a converted gamma-ray of energy 525.3 kev.

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

SATURDAY MORNING AT 10:00

Department of Commerce Auditorium

(E. C. POLLARD presiding)

Reactions of Transmutation, I

W1. Investigation of the T(T,2n)He^4 Reaction.* *Los Alamos Scientific Laboratory.*—The T(T,2n)He^4 reaction is being investigated using the Los Alamos 2.5-Mev electrostatic generator to accelerate tritons. The total neutron yield as a function of laboratory angle has been measured between 0° and 100° for tritons having energies of 0.6 and 0.8 Mev. The cross section varies between 0.011 and 0.0075 barn in this range. The yield at 0° and 90° as a function of triton energies from 400 kv to 1.4 Mev has been measured. It is reasonable to imagine the T−T reaction as taking place by any of the following reaction mechanisms:

$$\begin{aligned} \mathrm{T+T} &= \mathrm{He^4}+2n_0+Q \\ &= \mathrm{He^5}+n_0+Q_2=\mathrm{He^4}+2n_0+Q \\ &= \mathrm{He^4}+n_0{}^2+Q_3=\mathrm{He^4}+2n_0+Q_4. \end{aligned}$$

In order to differentiate between the various possible reactions an analysis of the energies of the α-particles as a function of angle was made. The maximum α-energy possible at any angle is that obtained when the two neutrons come off in the same direction; either as separate particles or as a dineutron having zero binding energy. If the dineutron is produced an α-group is to be expected which should vary with angle in a predictable manner. Preliminary evidence for such a group has been observed.

* This paper is based on work performed under Government Contract at the Los Alamos Scientific Laboratory of the University of California.

W2. The T+T Reaction: II. Energy Distribution of the Neutrons. J. H. SANDERS, K. W. ALLEN, E. ALMQVIST, J. T. DEWAN, AND T. P. PEPPER, *Chalk River Laboratory.*—The spectrum of the neutrons from the T+T reaction has been measured by observation of the recoil protons in Ilford C2 emulsions. A 200-μA beam of 220-kev ions containing about 10 percent tritons was focused into a 5-mm diameter spot on a brass target (see previous abstract). Plates were placed at 0° and 90° to the beam direction and measurements on the plates were made under well-defined geometrical conditions to ensure a small error in the derived neutron energy. The neutron spectrum shows a continuous distribution of energies from below 1 Mev to an upper limit of 9.5 Mev. This corresponds to the production of neutrons from the reaction T(t,2n)He^4. There is evidence for a small peak on the spectrum between 8.5 and 9 Mev, which can be attributed to the formation of He^5 in its unstable "ground" state. Fewer than 10 percent of the neutrons are formed in this way. A few 14-Mev neutrons were detected, due presumably to the T(d,n)He^4 reaction. The maximum intensity of the neutrons from T(t,2n)He^4 lies at about 4 Mev and the shape of the continuous spectrum is in general agreement with the expected distribution from the three-body disintegration.

W3. The T+T Reaction: I. Energy Distribution of the α-Particles. K. W. ALLEN, E. ALMQVIST, J. T. DEWAN, T. P. PEPPER, AND J. H. SANDERS, *Chalk River Laboratory.*—A 90° magnetic analyzer[1] has been used to obtain the momentum distribution of α-particles from the reaction T+T = He^4+2n^1+11.4 Mev at a triton bombarding energy of 220 kev. Sufficient intensity was obtained by bombarding a brass plate with a 200-μA beam containing 10 percent tritons, some of which were absorbed on the brass and acted as a target. The resolution used was about three percent in momentum. The α-particles were detected by recording scintillations from a ZnS or KI screen with an RCA 5819 photo-multiplier. A continuous distribution of α-particles, extending up to 3.8 Mev, was obtained. The distribution showed a broad maximum at about 2.7 Mev. Superposed on this distribution was a 3.5-Mev group of α-particles from the D+T reaction. The presence of this group can be explained by the natural deuterium content of the gas used and the high yield of the D+T reaction at low energies.[2] The energy distribution of the α-particles was also studied with a thin window proportional counter. The results were in agreement with those obtained by magnetic analysis.

[1] Burcham and Freeman, Phil. Mag. **40**, 807 (1949).
[2] Allan and Poole, Nature **164**, 102 (1949).

W4. Yield of He^3 and Scattered Protons from Li^6+P.* S. BASHKIN, F. AJZENBERG, C. P. BROWNE, GERSON GOLDHABER, M. J. W. LAUBENSTEIN, AND H. T. RICHARDS, *University of Wisconsin.*—Ordinary lithium targets (10–50 kev thick) evaporated on 1/20 and 1/50 mil thick nickel foils have been bombarded by monochromatic protons with energies from 0.440 to 3.5 Mev. Particles at 164° to the beam were observed with a 90° magnetic analyzer having two percent momentum resolution. This resolution plus pulse-height discrimination in a thin window proportional counter permitted identification of protons scattered from Li^6, Li^7, C^{12}, O^{16}, and

the nickel foil, and He^3 particles from $Li^6(p,\alpha)He^3$. Elastically scattered protons from Li^6 showed an asymmetric resonance (450-kev width at half-maximum) at $E_p=1.8$ Mev. The He^3 particles showed a similarly broad resonance, but with the maximum at $E_p=1.9$ Mev. These resonances indicate a level in Be^7 at 7.1 Mev, probably corresponding to the 7.38-Mev state of the mirror nucleus, Li^7. The He^3 yield was observed down to $E_p=0.440$ Mev, but resolution problems limited the low energy proton observations to $E_p>850$ kev. There is some indication from the low energy He^3 and scattered proton data of another resonance at low proton energy.

* Work supported partly by the AEC, partly by the Wisconsin Alumni Research Foundation.

W5. Yield of Scattered Protons from Li^7.* H. T. Richards, S. Bashkin, D. S. Craig, D. Donahue, V. R. Johnson, and D. Martin, *University of Wisconsin.*—The method and equipment described in the foregoing abstract was used to examine the yield at 164° of elastically and inelastically scattered protons from Li^7 for proton energies up to about 3.5 Mev. The elastically scattered protons could only be resolved satisfactorily for $E_p>850$ kev. The well-known resonance at $E_p=1.05$ Mev was observed, but no other structure was detected below $E_p=1.87$ Mev. A weak maximum (30 kev wide at half-maximum) occurred at this energy. This level, which is below the threshold for neutron emission, may be that suggested by Breit and Bloch[1] to explain the observed neutron yield from $Li^7(p,n)Be^7$. An intense and broad maximum is observed at $E_p\approx2.06$ Mev. After passing through a minimum at $E_p\approx2.25$ Mev, there is a rise until $E_p=2.5$ Mev, above which the yield is almost constant. The inelastically scattered protons could only get through the counter window for $E_p>1.5$ Mev. No structure was observed in the inelastic scattering yield up to $E_p=3.5$ Mev.

* This work supported partly by the AEC, partly by Wisconsin Alumni Research Foundation.
[1] G. Breit and I. Bloch, Phys. Rev. **74**, 397 (1948).

W6. Neutrons from the Disintegration of Li^7 by Deuterons.* W. D. Whitehead, *Bartol Research Foundation of The Franklin Institute.*—A thin target (~100 kev) of Li_2SO_4 (99.8 percent Li^7)† was bombarded with 1.1-Mev deuterons supplied by the Bartol Van de Graaff generator, and the reaction neutrons were recorded in 100μ Ilford C2 emulsions making an angle of 0 degrees with the beam and mounted 10 cm from the target. The range distribution of the recoil protons of less than 5.6 Mev gives evidence of two groups of neutrons with Q-values of 0.3 and 3.9 Mev superposed on the continuous group of neutrons from $Li^7(d,\alpha)He^5$, $He^5\rightarrow\alpha+n$. These neutron groups indicate levels in Be^8 at 14.7 and 11.1 Mev.

* Assisted by the joint program of the ONR and AEC.
† Obtained from Y-12, Carbide and Carbon Chemicals Corporation, Oak Ridge, Tennessee.

W7. The Excited Nuclear State of Be^7.* Geo. D. Freier, L. Rosen, and T. F. Stratton, *University of Minnesota and Los Alamos Scientific Laboratory.*—Ilford nuclear emulsion plates were exposed to neutrons from the $Li^7(p,n)Be^7$ reaction, produced by bombarding a 35-kev thick metallic Li target with 3.49-Mev protons from the Minnesota electrostatic generator. The plates were at 0° with respect to the proton beam. In the reading of the emulsions only those knockon proton tracks were accepted which made an angle of 10° or less with the direction of the incident neutron beam. The actual x, y, z coordinates of the tracks were measured, and the angle and track length were used to find the energy of the incident neutron. Two groups of tracks were found. The best estimate of the peak separation at this time is 460 ± 15 kev, with 0.10 ± 0.03 of the tracks falling into the lower energy group. The difference in the Q-values for the reactions leading to the ground state and the excited state of Be^7 is 428 ± 15 kev, in agreement with previous experimenters.[1-3] The data will be presented in the form of curves.

* Work supported in part by ONR.
[1] Brown, Chao, Fowler, and Lauritsen, Bull. Am. Phys. Soc. **24**, No. 8, 11 (1949).
[2] Lauritsen and Thomas, Bull. Am. Phys. Soc. **24**, No. 8, 11 (1949).
[3] Johnson, Laubenstein, and Richards, Phys. Rev. **77**, 413 (1950).

W8. Angular Yield of Deuterons and Alphas from the Proton Bombardment of Be^9. J. A. Neuendorffer, D. R. Inglis,* and S. S. Hanna, *The Johns Hopkins University.*†—A Be foil was mounted in a semicircular chamber with seven photographic plates arranged inside at positions 25° apart and 22 cm from the target. The product alphas and deuterons were separated from the scattered protons by passing through gaps in a semicircular yoke of an electromagnet. Thus, the method combines the advantages of magnetic deflection and simultaneous photographic recording. The deuteron distribution exhibits principally a $1+a\cos\theta$ dependence, especially between 600 and 1000 kev, the coefficient a increasing with energy. The alpha-distribution appears to be somewhat similar, which perhaps reflects the fact that the two final nuclei are 0^+ and 1^+. The strong interference term requires states of the compound nucleus of opposite parity. Identifying these with states previously observed[1] it seems reasonable to ascribe the strong resonance at 330 kev to entering s-waves, and the higher resonance to p-waves. Stopping powers of Ilford C2 emulsions for protons, deuterons, and Li^6 nuclei of energies up to 1 Mev, and for alphas up to 2 Mev, and equilibrium ratios of He^+ to He^{++} and of Li^+ to Li^{++} ions as they leave the target were also measured.

* Now at the Argonne National Laboratory.
† Assisted in part by the AEC.
[1] Thomas, Rubin, Fowler, and Lauritsen, Phys. Rev. **75**, 1612 (1949).

W9. Neutron Spectrum from Proton Bombardment of Beryllium.* V. R. Johnson, M. J. W. Laubenstein, and F. Ajzenberg, *University of Wisconsin.*—A thin foil of Be, 1.7 microns thick, was mounted on a tantalum backing and bombarded with 3.815-Mev protons produced by the Wisconsin electrostatic generator. Eastman NTA nuclear emulsion plates 100 microns thick were mounted four inches away from the target at angles of 0°, 45°, and 90° with respect to the incident beam. A total of 400 tracks have been measured on the 0° plate. A plot of this data, after being corrected for variation of the $n-p$ scattering cross section and for geometry, shows clearly the group from the ground state transition of the reaction $Be^9(p,n)B^9$ with a half-width of the curve of about 0.12 Mev. There is also observed a continuous distribution of neutrons extending from the ground state group down to low energies. The average ordinate of this continuous distribution is less than one-tenth the height of the ground state peak. Comparison with the earlier $Li^7(p,n)Be^7$ spectrum measurements under similar geometry indicates that this continuous distribution does not result from scattered neutrons. These low energy neutrons can be attributed to the $Be^9(p,pn)Be^8$ reaction. Measurements on the other plates are in progress.

* Work supported partly by the AEC, partly by the Wisconsin Alumn Research Foundation.

W10. Pair Spectrum of Gamma-Rays from Polonium-Beryllium.* James Terrell,† *Rice Institute.*—A pair spectrometer using 180° focusing has been used in the investigation of the polonium-beryllium gamma-ray spectrum from a two-curie source (on loan from Los Alamos). A single peak has been found, corresponding to a 4.3-Mev gamma-ray from the reaction $Be^9(\alpha n,\nu)C^{12}$. No indications of other gamma-rays have been found in the range 2 to 10 Mev. Since the sensitivity of the spectrometer increases rapidly with energy, and background counting rates (with no radiator) are low in the high energy region, there is good evidence that no important gamma-radiation exists above 4.3 Mev. Below the main peak

the sensitivity is lower and the background more important, so that lower energy gamma-rays have not been entirely ruled out. Previous investigators[1,2] have reported gamma-radiation of 2.7, 4.2, and 6.7 Mev. The 2.62-Mev gamma-ray from ThC″ has been used to check the operation of the spectrometer. Other high energy gamma-rays are to be investigated.

* Assisted by the joint program of the ONR and AEC.
† AEC predoctoral fellow.
[1] W. Bothe, Zeits. f. Physik **100**, 273 (1936).
[2] B. S. Dzelepov, Comptes Rendus U.R.S.S. **23**, No. 1, 24 (1939).

W11. Excitation Levels in B^{10}. T. W. Bonner, J. W. Butler, and J. R. Risser, *Rice Institute.**—Excited states in B^{10}, resulting from the reaction $Be^9(d,n)^*B^{10}$, have been studied by the method of neutron thresholds. The prominent level in B^{10} at 5.0 Mev was investigated with monoenergetic deuterons near the neutron threshold of 920 kev. The observed shape of the threshold curve shows that the width of this excited level is less than 2 kev although it usually breaks up into Li^6+He^4 +0.8 Mev, instead of returning to ground state with γ-emission.[1] Four additional thresholds were observed with deuterons of energies from 920 to 1070 kev. In contrast to these results no additional levels were found with deuteron energies of from 750 to 920 kev.

* Supported by the joint program of the ONR and AEC.
[1] Chao, Lauritsen, and Rasmussen, Phys. Rev. **76**, 582 (1949).

W12. Excitation Curves for $B^{10}(d,p)B^{11}$. G. C. Phillips, *Rice Institute.**—The excitation curves for the longest range proton group of the reaction $B^{10}(d,p)B^{11}$ have been determined in the bombarding energy range of 0.7 to 2.0 Mev at the three laboratory angles of 0°, 90°, and 135° to the direction of the bombarding deuterons. The deuterons, accelerated by the Rice Pressure Van de Graaff, bombarded thin targets of B_2O_3 evaporated in a vacuum onto thin silver foils ($\sim$15 mg/cm^2). The B_2O_3, enriched to 96 percent in B^{10}, was obtained from Oak Ridge. The protons were counted by a proportional counter-linear amplifier combination that was biased to count all protons passing through the counter. Aluminum foils placed between the target and the counter stopped all but the energetic group of protons. The excitation curves so obtained indicate at least two broad resonances in this energy region corresponding to excitation levels of C^{12} in excess of 25.5 Mev. The angular distributions of these protons are not spherically symmetrical.

* Assisted by the ONR and AEC.

W13. Energy Levels in B^{11} from the $B^{10}(d,p)B^{11*}$ Reaction.* W. W. Buechner and D. M. Van Patter, *M.I.T.*—The proton groups from thin targets of B^{10} (96 percent enriched) were observed at 90° with a 180° focusing magnetic spectrometer, using 1.5-Mev deuterons. The proton groups assigned to the $B^{10}(d,p)B^{11}$ reaction gave corresponding Q-values of 9.279; 7.128; 4.804; 4.225; 2.500; 2.450; 1.95; 0.68; and 0.32 Mev with a probable error of less than 20 kv. The last five proton groups were assigned by comparison of the relative yield from enriched B^{10} with that from natural boron targets. This was necessary to eliminate the proton groups from surface contaminants of carbon, oxygen, and nitrogen, which in many cases were more intense than the proton groups from B^{10}. A doublet is indicated in B^{11} at 6.8 Mev with a separation of 50 ± 5 kv. However, the group with $Q=2.450$ was about one-fifth as intense as the group with $Q=2.500$ Mev, and its assignment is less certain. The possibility that other doublets may exist is being investigated. These results are in general agreement with those recently reported by Bateson[1] considering the increased resolution in these experiments.

* This work was assisted by the joint program of the ONR and AEC.
[1] Bateson, Bull. Am. Phys. Soc. **25**, No. 1, 32 (1950).

W14. Ground State of B^{12} from the $B^{11}(d,p)B^{12}$ Reaction.* E. N. Strait, D. M. Van Patter, and W. W. Buechner, *M.I.T.*—The proton groups from thin targets of natural boron bombarded by 1.5-Mev deuterons have been analyzed at 90° with a magnetic spectrometer. Two groups were found which disappeared when the natural boron target was replaced by an enriched B^{10} target (4 percent B^{11}). Assuming these arise from the $B^{11}(d,p)B^{12}$ reaction, the Q-values are 1.136 ± 0.004 and 0.189 ± 0.004 Mev, corresponding to the ground state of B^{12} and an excited state at 0.947 ± 0.006 Mev. The relative intensities of the proton groups are about 3:1. The assignment of the high energy group, which was just resolved from the more intense $O^{16}(d,p)O^{17*}$ group, was confirmed by observing that the Q-value remained constant to 1 kv, when the bombarding energy was changed from 1.5 to 0.7 Mev. This result does not agree with that of Hudspeth and Swann,[1] who assign a group with $Q=1.25$ Mev and 1/60 the intensity of the lower energy group to the ground-state reaction. Comparison of $Q_0=1.136$ Mev with Hornyak and Lauritsen's[2] measurement for the end point of the beta-spectrum from B^{12} indicates that the beta-decay of B^{12} occurs primarily between the ground states of B^{12} and C^{12}.

* This work was assisted by the joint program of the ONR and AEC.
[1] Hudspeth and Swann, Phys. Rev. **76**, 1150 (1949).
[2] Hornyak and Lauritsen, Phys. Rev. **77**, 160 (1950).

Saturday Afternoon at 2:15

Department of Commerce Auditorium

(C. C. Lauritsen presiding)

Reactions of Transmutation, II

X1. Nuclear Energy Levels in Nitrogen (14) and Aluminum (27).* C. P. Swann and C. E. Mandeville, *Bartol Research* Foundation.—Ilford C_2 emulsions, making an angle of zero degrees with the bombarding beam, were irradiated by neutrons from the reaction $C^{13}(D,n)N^{14}$. The incident deuterons were supplied with an energy of 1.43 Mev by the Bartol Van de Graaff statitron. The target of C^{13} (isotopic concentration 50 percent) had a thickness of 100 kev. Neutron groups were observed corresponding to Q-values of 0.27, 1.30, 1.68, and 5.24 Mev giving energy levels in N^{14} at 4.97, 3.94, and 3.56 Mev. The group of lowest Q has been previously reported by the Rice group.[1] The intermediate Q-values offer a possible explanation for recently observed gamma-rays.[2] When a thick target of isotopic Mg^{26} was irradiated by deuterons, eight groups of neutrons were observed corresponding to energy levels in Al^{27} at 0.88, 1.92, 2.75, 3.65, 4.33, 5.32, and 5.81 Mev.

The Q-value for the ground state is 5.68 Mev. The level structure closely resembles that obtained by other methods; e.g., proton scattering by aluminum.

* Assisted by the joint program of the ONR and the AEC.
[1] Bennett, Bonner, Hudspeth, Richards, and Watt, Phys. Rev. **59**, 781 (1941).
[2] R. G. Thomas and T. Lauritsen, Bull. Am. Phys. Soc. **24**, No. 8, 11 (1949).

X2. Formation of N^{17} by Gamma-Ray Bombardment of O^{18}.* R. SHER, J. HALPERN, AND W. E. STEPHENS, *University of Pennsylvania.*—Following the suggestion of Charpie *et al.*,[1] the reaction $O^{18}(\gamma,p)N^{17}$ has been investigated by irradiating 250 cc of normal water with bremsstrahlung from the University of Pennsylvania 25 Mev betatron. The sample was irradiated close to the betatron target for 15 sec. at a beam intensity of about 100 roentgens per minute (measured at three feet from the target). The betatron was then turned off and the pulses from an enriched $B^{10}F_3$ counter placed behind the sample were recorded. A delayed neutron activity of 4.25 ± 0.5 sec. was found, indicating the presence of N^{17} (half-life 4.14 ± 0.04 sec.).[2] The threshold energy was found to be 18.2 ± 0.3 Mev, whereas the calculated Q-value is -15.9 Mev.[1] The difference is ascribed to effects of the Coulomb barrier. Various tests confirmed the supposition that the reaction $O^{17}(n,p)N^{17}$ was not being observed here.

* Supported by the joint program of the AEC and ONR.
[1] Charpie, Sun, Jennings, and Nechaj, Phy. Rev. **76**, 1255 (1949).
[2] Knable, Lawrence, Leith, Moyer, and Thornton, Phy. Rev. **74**, 1217 (1948).

X3. Concentration of Argon 36 and Study of the $A^{36}(d,p)A^{37}$ Reactions.* A. ZUCKER AND W. W. WATSON, *Yale University.*—By means of a multi-stage thermal diffusion apparatus we have brought the concentration of argon 36 from its natural 0.35 percent to 95.9 percent. The apparatus consisted of six 2-meter concentric-cylinder columns, the first of which was used as a scrubber. The last concentric cylinder column was coupled convectively to a metal hot-wire column which had a 200 cc light end-volume. These 7 columns produced 200 cc of 20 percent A^{36} every 70 hours at a pressure of 1.1 atmospheres. This gas was transferred batchwise to a glass hot-wire column operating at 0.9 atmospheres and 1500°K. The light end-volume of the glass column contained 40 cc S.T.P. of 95.9 percent A^{36} at the end of each run. With this well-separated A^{36} we investigated the $A^{36}(d,p)A^{37}$ reactions previously studied by Davison *et al.*[1] The gas was bombarded with 3.9 Mev deuterons, and protons were counted at 90° with a proportional counter. We find a ground state Q at 6.49 Mev, and 7 excited states of the A^{37} nucleus with Q's of 5.05, 3.93, 2.95, 2.09, 1.86, 1.42, and 0.64 Mev.

* Assisted by the AEC.
[1] Davison, Buchanan, and Pollard, Phys. Rev. **76**, 890 (1949).

X4. Protons from the Deuteron Bombardment of Co^{59}. W. O. BATESON AND ERNEST POLLARD, *Yale University.**—In the lighter elements deuteron bombardment yields discrete groups of protons. This has not been extensively tested for more complex elements. A target of cobalt electrolyzed onto gold has been bombarded by deuterons and proton group structure looked for. It is clear that the group structure is complex and although several Q-values can be determined there are unquestionably many unresolved groups. The Q-values obtained are 5.19, 4.80, 4.38, 3.91, 3.46, 3.02 and 2.39 Mev. The yield of protons increases rapidly as the excitation increases. If the relation $D=C\exp(-BE^{\frac{1}{2}})$ is applied to the yield of protons on the assumption that the yield is proportional to the density of unresolved levels, a value for B of 1.5 ± 0.5 Mev results.

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

X5. Energy Levels in Lead, Bismuth and Thallium.* J. A. HARVEY, *M.I.T.*—Using 14 Mev deuterons from the cyclotron differential proton and triton spectra have been obtained from enriched** lead targets and bismuth and thallium targets. The proton spectra from all targets look very similar. Tentative Q values of ground states and excited levels (in Mev) correct to 0.1 Mev. are:

$Pb^{206}(d,p)Pb^{207}$	4.5, 3.6 (double),	1.8,	0.9,	0.0,	−0.8
$Pb^{207}(d,p)Pb^{208}$	5.1_5	1.7		0.0	−0.8
$Pb^{208}(d,p)Pb^{209}$		1.7	0.9(?)	0.1	−0.3 −0.8
$Bi^{209}(d,p)Bi^{210}$		1.95		0.3	−0.3 −0.8

Note the repetition of several of the Q values in all of the targets. The triton spectra from the 3 lead isotopes and bismuth target also look very similar to each other except for ground peaks. The energy levels of Pb^{207} obtained from triton spectra from Pb^{208} are in fair agreement with those obtained from the proton spectra of Pb^{206}.

* Assisted by joint program ONR and AEC.
** Supplied by Carbide and Carbon Chemical Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

X6. Energy Spectrum and Differential Cross Sections of (d,p) Reactions Using 14 Mev Deuterons.* HARRY GOVE AND KEITH BOYER, *M.I.T.*—The energy spectrum of protons emitted when thin targets are bombarded with 14 Mev deuterons was measured as a function of angle for several elements. From this an energy spectrum integrated over angle was obtained which will be compared with existing theories. The differential cross sections of (d,p) reactions has been measured as a function of angle and proton energy by measuring the total number of particles of a particular energy at a convenient angle. From the target thickness and the number of incident deuterons, absolute cross sections were calculated. The deuteron beam intensity was checked in three independent ways, by activity measurement, Faraday cup, and thermal heating. The total cross section for the (d,p) reaction was obtained by cutting the spectrum off at $Q=-2.2$ Mev and integrating over energy and angle. This was compared with (d,p) cross sections measured by activation techniques where they are known.

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

X7. Photo-Alpha-Reactions in Light Nuclei. T. A. WELTON, *University of Pennsylvania.*—If C^{12} is bombarded with x-rays there exists an energy region from 7.3 Mev to 16.0 Mev in which the only reaction possible is the disintegration of the nucleus into three α-particles. Similarly, with O^{16}, between 7.2 Mev and 12.1 Mev only the emission of a single α-particle is possible. If the O^{16} nucleus can be regarded approximately as a resonating structure of four α's, then the cross section for the reaction can be estimated simply, somewhat as is done for the deuteron photo-disintegration. The cross section is a product of the usual statistical factor, a barrier penetration factor, and the square of an electric quadrupole matrix element. The angular distribution is unambiguously given by $\sin^2\theta\cos^2\theta$, and the energy variation near threshold appears dependable also. Unfortunately, preliminary estimates indicate an implausibly high value, of the order of 10^{-24} cm^2, at 12 Mev. If the α-particle picture is not valid, then the quadrupole matrix element must be very greatly reduced to describe the difficulty of "assembling" the α-particle, so that careful experiments may give clear evidence on the structure of the nuclear wave function.

X8. Nuclear Reactions Induced by High Energy X-Rays. KARL STRAUCH, *University of California, Berkeley.*—Using the x-ray beam from the 335 Mev Berkeley synchrotron the average photon energy responsible for several nuclear reactions has been measured by the transition curve method previously described.[1,2] Results to date are: $C^{12}(\gamma,n)C^{11}$ 30 Mev;

$Cu^{63}(\gamma,n)Cu^{62}$ 20 Mev; $Zn^{64}(\gamma,n)Zn^{63}$ 21 Mev; $Ag^{107}(\gamma,n)Ag^{106}$ 18 Mev; $Zn^{64}(\gamma,2n)Zn^{62}$ 32 Mev; $Zn^{64}(\gamma,pn)Cu^{62}$ 34 Mev; $Ta^{181}(\gamma,2p\cdots)$ 70 minute rare earth 70 Mev. Unidentified short half lives are produced in bismuth and lead by 90 Mev photons. The relative yield of several reactions has been determined; taking the $C^{12}(\gamma,n)C^{11}$ yield as 1.0 we obtain: $Zn^{64}(\gamma,n)Zn^{63}$ 11; $Zn^{68}(\gamma,p)Cu^{67}$ 1.2; $Zn^{64}(\gamma,2n)Zn^{62}$ 0.7; $Zn^{64}(\gamma,pn)Cu^{62}$ 3.3; $Zn^{66}(\gamma,3n)Zn^{63}<0.4$; $Zn^{64}(\gamma,p2n)Cu^{61}$ 0.55. Further measurements will be presented and these results will be discussed with respect to the several models for x-ray induced reactions that have been proposed. This work was sponsored by the Atomic Energy Commission.

[1] K. Strauch, Bull. Am. Phys. Soc. **24** (No. 8), 8 (1949).
[2] L. Eyges, Bull. Am. Phys. Soc. **24** (No. 8), 8 (1949).

X9. Photo-Disintegration of Ag and Al.* B. C. DIVEN AND G. M. ALMY, *University of Illinois.*—Energy and angular distributions of photo-protons from Ag and Al have been studied. A metal foil was irradiated with a pencil of x-rays from a 22-Mev betatron. Protons from the foil were caught in two nuclear photographic plates at near-grazing incidence and at angles 20° to 160° from the beam. The proton spectrum from the Ag isotopes (proton thresholds near 6 Mev, barrier at 9.8 Mev), excited with x-rays of 20.8 Mev maximum energy, extends to 13 Mev with a peak at 6 or 7 Mev. The higher energy protons are emitted preferentially near 90°, as observed for Rh.[1] Comparison with theory shows that the observed spectrum is shifted to higher energies than predicted from a statistical level density[2] but lower than if all protons had the maximum available energy or than predicted from Schiff's "regular level" density.[3] The proton spectrum from Al (proton threshold at 9.2 Mev, barrier at 4.2 Mev) excited with 20.8 Mev x-rays, extends to 11 Mev with peak at 4 Mev and shows no angular asymmetry.

* Assisted by joint program of the ONR and AEC.
[1] Curtis, Hornbostel, Lee, and Salant, Phys. Rev. **77**, 290 (1950).
[2] V. F. Weisskopf and D. H. Ewing, Phys. Rev. **57**, 472, 935 (1940).
[3] L. I. Schiff, Phys. Rev. **73**, 1311 (1948).

X10. Neutron Yields from Photo-Disintegration by 17.6 Mev Gamma-Rays. R. L. WALKER,* B. D. MCDANIEL, AND M. B. STEARNS, *Cornell University.***—Measurements have been made of the relative yields of neutrons from 32 different elements when irradiated by gamma-rays from the $Li^7(p,\gamma)Be^8$ reaction. The absolute yield has been measured for copper. The neutrons emitted from each sample were detected by four BF_3 proportional counters embedded with the sample in a large block of paraffin. With the exception of Ca, Ni and U, the elements examined yield values which fall within 15 percent of a smooth curve. This curve increases rapidly with increasing Z up to Z equal 74, then begins to decrease slightly. Representative yields relative to Cu are: Al 0.096, Cl 0.25, Ca 0.027, Ti 0.54, Co 0.83 Ni 0.41, Mo 2.6, Ce 4.2, W 5.9, Hg 4.7, Pb 4.5, Bi 4.5, and U 9.0. A calibrated RaBe source was used to determine the counter efficiency. Absolute gamma-ray intensity was determined in two ways: (1) by using a gamma-ray pair spectrometer, (2) by using a thin walled Geiger counter located in a broad region of magnetic field. The counter measures the number of Compton and pair processes occurring in thin radiators located immediately ahead of the counter. The tentative cross section for Cu is 0.068 ± 0.012 barn. Indication of the relative energy spectra of neutrons was obtained.

* Now at California Institute of Technology.
** Assisted by ONR.

X11. Photo Neutron Thresholds for Pb^{206}, Pb^{207}, Pb^{208}.* H. PALEVSKY AND A. O. HANSON, *University of Illinois.*—Separated lead isotopes obtained from Oak Ridge were irradiated by electrons from the 22 Mev betatron and the number of neutrons emitted was measured as a function of the electron energy. The experimental apparatus utilized the electron beam, focused on copper sample holders at about eleven feet from the betatron. This reduced the background neutrons from the betatron to a negligible amount. Gated BF_3 proportional counters were used to detect the neutrons after each electron burst. Two samples were rotated synchronously in front of the beam, so that each was irradiated on alternate bursts. The yield *versus* energy data could, in each case, be represented as a parabola with the vertex at the respective threshold. The analysis gave the following thresholds based on the $Cu^{63}(\gamma,n)$ threshold of 10.9 Mev: Pb^{206}, 8.25 ± 0.10 Mev; Pb^{207}, 6.95 ± 0.10 Mev; Pb^{208}, 7.44 ± 0.10 Mev. The relative (γ,n) cross sections near threshold were as follows: Pb^{206}, 1.00; Pb^{207}, 0.80 ± 0.02; Pb^{208}, 0.99 ± 0.02.

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

SATURDAY AFTERNOON AT 2:15

National Academy

(M. L. POOL presiding)

Invited Paper

Y1. Recent Work on Nuclear Isomers. M. GOLDHABER, *University of Illinois.* (40 min.)

Beta-Emitters, II

Y2. Radiations of Sn^{123} and Sn^{125}.* B. H. KETELLE, C. M. NELSON, AND G. E. BOYD. *Oak Ridge National Laboratory.*—Samples of electromagnetically enriched Sn^{124} (52.0 ± 1.0 percent) and Sn^{122} (70.7 ± 1.0 percent) have been activated by prolonged irradiations in high slow neutron fluxes. Chemical separations were performed to purify the tin and to remove radioactive antimony and tellurium daughters. The beta-distributions of the 9.9 d Sn^{125} and 136 d Sn^{123} were obtained with a thin magnetic lens beta-ray spectrometer which gave end-point energies of 2.33 ± 0.01 and 1.42 ± 0.01 Mev, respectively. Both beta-ray distributions differed markedly from that for an allowed transition. The spectrum shapes were shown to correspond to that for a once forbidden transition with a spin change of two and a change in parity. The only conversion electron peaks observed in both sources were attributed to the 390-kev gamma-ray of In^{113} and to the 152-kev gamma-ray of Sn^{117} formed by neutron capture by the small amounts of Sn^{112} and Sn^{116} in the enriched preparations. The foregoing radiation characteristics and energy values were confirmed by absorption techniques using Al, Cu, and Pb.

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

Y3. Radiations from Cerium (144)$\xrightarrow{\beta}$Praseodymium (144)$\xrightarrow{\beta}$ Neodymium (144).* C. E. MANDEVILLE AND E. SHAPIRO, *Bartol Research Foundation.*—Ce^{144}, in equilibrium with its 17-minute daughter activity, Pr^{144}, was separated from fission fragments at the Oak Ridge pile. After further chemical purification, coincidence, and absorption measurements were made of the emitted radiations. The beta-rays of the 300-day Ce^{144} were found to have a maximum energy of 0.36 Mev, and the very hard beta-rays of Pr^{144} have an end point at 2.87 Mev. A source of the two radionuclides in equilibrium emits x-rays at 36 kev and gamma-rays having a mean energy of 1.67 Mev as determined by absorption curves in lead and aluminum. A coincidence absorption curve indicated that a hard gamma-ray at 2.60±0.15 Mev is emitted in the disintegration of Pr^{144}. The beta-gamma-coincidence rate of Pr^{144} was observed to decrease from an extrapolated value of 0.02×10^{-3} coincidence per beta-ray at zero absorber thickness to zero at an approximate beta-ray energy of 0.42 Mev. The magnitude of the coincidence rate and the calibration of the gamma-ray counter indicate that two percent of the beta-rays of Pr^{144} are coupled with the hard gamma-radiation. Gamma-gamma- but no beta-beta-coincidences were found in $Ce^{144}-Pr^{144}$.

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

Y4. Disintegration of Yb^{169}. E. N. JENSEN, L. J. LASLETT, R. T. NICHOLS, AND W. W. PRATT, *Iowa State College.**—The 33-day Yb^{169} was produced by neutron bombardment of ytterbium oxide[1] in the Clinton pile. The radiations were examined in a magnetic lens spectrometer more than a month after the sample was irradiated in the pile. The internal conversion spectrum and the photo-electron spectrum with a Pb radiator were determined. The low energy end of the photoelectron spectrum was also determined, with Ag and Sn radiators. The data indicate that Yb^{169} decays by K-capture to Tm^{169}. Ten gamma-rays were found having energies of 63.7±0.3, 94.5±0.9, 110.4±0.6, 120.4±1.2, 132.6±1.3, 142.6±1.4, 160.0±1.6, 177.9±0.9, 198.3±2, and 308.0±1.5 kev. A tentative decay scheme will be discussed.

* This work was performed at the Ames Laboratory of the AEC.
[1] The ytterbium oxide was kindly furnished by Dr. F. H. Spedding, P. E. Porter, and J. M. Wright of this laboratory.

Y5. The Doubtful Decay of Au^{198}.* PHILIP S. JASTRAM, W. KONNEKER, AND MARSHALL R. CLELAND, *Washington University.*—Conflicting reports on the existence and half-life of a short-lived metastable state in the disintegration of Au^{198} suggested a repetition of the lifetime measurement in the hope of clearing up some of the fog. Samples of this isotope prepared from Au^{197}, either by slow neutron bombardment in the Oak Ridge pile or by deuteron-bombardment in the Washington University cyclotron, were examined by means of a delayed-coincidence technique using scintillation counters. All yielded a metastable state having a half-life of 0.04±0.01 microsecond. The parent of this activity was found to have a half-life of 4 hours rather than 2.7 days, and consequently after one or two days subsequent to activation of the source, the short-lived state had vanished in the background produced by the well-known beta-spectrum and gamma-radiation decaying at the 2.7-day rate. This effect may account for the failure of some observers to find the short-lived transition. Deuterons and fast neutrons on Au^{197} yield Hg^{197} as well as Au^{198}; however, investigation of proton-bombarded Au^{197}, which produces only Hg^{197}, yielded no short-lived metastable state. The decay scheme of Au^{198} will be discussed in the light of these results and of subsequent work.

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

Y6. $\beta-\pi$-Angular Correlation Measurements.* ROBERT STUMP† AND SHERMAN FRANKEL, *University of Illinois.*—$\beta-\gamma$-angular correlation measurements on Au^{198} and Rb^{86} have been repeated and measurements on Cb^{95} and Cs^{134} carried out. The previously reported isotropy in Au^{198} [1,2] and Cs^{134} [2] is verified. (To accentuate any correlation effect in Cs^{134} we have also made measurements with the β-scintillation counter biased to accept only the upper 7 percent of the β-spectrum.) Isotropy is also found for Cb^{95}. These isotropies are consistent with the allowed shapes of the beta-spectra. With an improved arrangement the previously reported results[1] for Rb^{86} are shown to be in error. The correlation function for Rb^{86} was found to be compatible with a distribution $W(\theta)=1+R/Q\cos^2\theta$. Using this function as the basis for evaluating the data from the other isotopes as well, we obtain: R/Q (Rb^{86})$=0.057\pm0.01$; R/Q (Cs^{134})$=0.0016\pm0.006$; R/Q (Au^{198})$=-0.005\pm0.02$; R/Q (Cb^{95})$=0.0034\pm0.02$. The data for Rb^{86} are corrected for the finite solid angle of the detectors (β-counter$=0.03$ steradian; γ-counter$=0.07$ steradian). They are in essential agreement with recent M.I.T. data.[3] Probable errors indicated are statistical.

* Work supported in part by ONR and AEC.
† AEC Predoctoral Fellow.
[1] S. Frankel, BAPS 24–7 (1949).
[2] R. L. Carwin, Phys. Rev. **76**, 1876 (1949).
[3] M. Deutsch (private communication).

Y7. Beta-Gamma-Angular Correlation in Rb^{86}, Au^{198}.* S. L. RIDGWAY,† *Princeton University.*—Beta-gamma-angular correlation was investigated with anthracene scintillation counters, dry ice cooled 1P21's, Los Alamos 501 amplifiers, and tenth-microsecond coincidence circuit. The beta- and gamma-counters, 5 cm distant from the source, subtended solid angles 0.12 and 0.08 steradian respectively. They were enclosed in a large evacuated chamber, the gamma-counter being rotated. The coincidence rate was normalized by the single rate in each channel to correct for variation in solid angle of the gamma-counter and drifts (~1 percent) in counter efficiency. For Au^{198} $C(180°)/C(90°)=1.004$, standard deviation 0.015; for Rb^{86} these quantities were 1.019; 0.014. The result for Au^{198} agrees with those of Frankel[1] and Garwin.[2] That for Rb^{86} is consistent with isotropy, and disagrees with Frankel's 9.4 percent effect. Tests were made that ruled out the possibility of scattering from one counter to another having an appreciable effect.

* Assisted by the joint program of the ONR and AEC.
† NRC Predoctoral Fellow (1946–1949).
[1] Sherman Frankel, Phys. Rev. **77**, 747 (1950), Bulletin, American Physical Society **24**, No. 7, 14 (1949).
[2] Richard L. Garwin, Phys. Rev. **76**, 1876L (1949).

Y8. A Mass Spectrometric Investigation of Branching in Neutron Inducer Activities. JOHN H. REYNOLDS, *Argonne National Laboratory.*—An investigation of branching in several neutron induced activities has been made mass spectrometrically. The method consists in subjecting gram quantities of the elements under investigation to prolonged neutron irradiation, allowing the (n,γ) activities to decay, and determining the amounts of the transmuted elements present. By use of an isotope dilution technique, these amounts can be determined with precision. A carefully weighed amount of the daughter element, with isotopic constitution *different* from that of the radiogenic material, is added as a tracer to a solution of the irradiated sample. Once isotopic mixing has occurred, results are independent of the yield of a subsequent chemical separation of the parent and daughter elements. Yields are calculated, instead, from the change in the isotopic constitution of the tracer. The elements Cu, Br, and I were irradiated, requiring mass spectrometer observations on Ni, Zn, Se, Kr, Te, and Xe. Preliminary calculations give the following values for the branching ratio (ratio of $Z\rightarrow Z-1$ transitions to $Z\rightarrow Z+1$ transitions):

Cu^{64} 1.62±0.11; Br^{80} 0.090±0.002; $Br^{82}<0.0003$
I^{128} 0.053±0.002.

The transition $I^{128}\rightarrow Te^{128}$ has not been reported heretofore and

is probably due to K-capture accompanying the 25 minute negatrons. Results of final calculations will be presented and compared with theory.

Y9. System for the Study of Short-Lived Radioactive Gases.* MICHEL TER-POGOSSIAN, FRED T. PORTER, AND C. SHARP COOK, *Washington University.*—The study of low "Z," short-lived radioactive gases is of theoretical interest. A number of serious problems arise, both in the adequate control of production of the radioactivity and also in the analysis of the radiation emitted by such a radioactive source. To provide a suitable means for such studies a system has been constructed in this laboratory whereby a gas may be circulated continuously between the cyclotron and the 14-cm radius of curvature magnetic spectrometer. At the cyclotron end of this system is a large aluminum bombardment chamber. At the spectrometer end a specially constructed source holder allows magnetic analysis of the charged particle radiations from the radioactive gas. The gas under study is activated continuously in the bombardment chamber and circulated by means of two mechanical pumps through the system. Foils may also be mounted within the bombardment chamber in order that certain gaseous souces may be produced from solid target materials. In this case the radioactive gas is carried through the system by a flushing gas, this to date being helium.

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

Y10. Measurements of the Relative Transmission of Beta-Particles Through Thin Zapon Windows.* C. SHARP COOK AND CHIA-HUA CHANG, *Washington University.*—It has been known for some time that the relative number of beta-particles that are transmitted through a foil is a function of the energy of the incident beta-particles. This transmission coefficient gradually rises from a value of zero at the low energy cut-off of the window to a value approaching 100 percent at an energy several times that of the cut-off energy. The transmission curves for various thicknesses of Zapon Geiger-Mueller counter windows as a function of energy are being prepared. The method in use measures the increase in counting rate at each point in the lower energy region of a continuous beta-spectrum when the beta-particles are electrostatically accelerated at the source. The fact that the slope of the transmission curve is the same for a g ven energy of emitted electron for all voltages applied to the source indicates that the application of voltage to the source in the current experiment does not distort the direction of emission of the beta-particles. Curves obtained thus far for Zapon are in relatively good agreement with the curves obtained for Nylon by the St. Louis University group.[1]

* Assisted by the joint program of the ONR and AEC.
[1] Sturcken, Heller, and Weber, Bull. Am. Phys. Soc., New York meeting (1950).

SUPPLEMENTARY PROGRAMME

SP1. A Fast Multiplying Circuit.* B. CHANCE AND J. BUSSER, *University of Pennsylvania* AND F. C. WILLIAMS, *University of Manchester.*†—In the course of the development of a fast analogue computer for displaying families of curves for the solutions of differential equations representing biochemical reactions, a new version of the "quarter-square" multiplication method[1] has been developed. A single parabolic characteristic is used to square the amplitudes of alternate half-cycles of an 82KC/sec. square wave which represent the quantities $A+B$ and $A-B$. The difference of the squares gives the desired product $4AB$. The parabolic characteristic itself covers a scale of more than 25 volts and consists of a series of fifteen or more segments approximating a true parabola with an error of less than 0.4 percent. The slope of the segments is determined by the value of the input voltage which in turn determines the number of diodes contributing to the output current. This segmented non-linear element is stable and predictable. The circuit gives the product of the inputs every 12 μsec. with an error of less than one percent.

* To be given after Session N if the Chairman rules that time permits.
† Supported by the ONR.
[1] D. J. Mynall, Electronic Engineering **19** (June-September 1947).