Proceedings of the American Physical Society

MINUTES OF THE SEMI-CENTENNIAL MEETING AT CAMBRIDGE, JUNE 16–18, 1949

THE 293rd meeting of the American Physical Society was held on Thursday, Friday, and Saturday, June 16, 17, and 18, 1949, in the buildings of Harvard University and the Massachusetts Institute of Technology in Cambridge, Massachusetts. This was designated as the Semi-Centennial Meeting of the Society, and comprised ceremonial features and speeches in commemoration of the foundation of the Society and the first fifty years of its history. The Society was organized on May 20, 1899 by a group of some forty physicists; six of them—Wilder L. Bancroft, Bergen Davis, Frederick L. Bedell, Marcia A. Keith, Isabelle Stone, and F. A. Waterman—are living, but unfortunately none of these was able to be present at this celebration. (Of those who are known to have been present at the first "regular" meeting of the Society —that of October 28, 1899—G. B. Pegram and L. P. Wheeler attended this meeting, and quite probably others were there.) Five hundred and ninety-three people registered, making this by far our largest summer meeting except for that of June 1946 when a great deal of work in nuclear physics emerged from classification. The Local Committee, headed by Otto Oldenberg and comprising Norman Ramsey, Roger Hickman, John C. Slater, A. E. Benfield, and many who helped them, handled its difficult work admirably well. The weather was warm and humid but might have been worse.

The Ceremonial Session was held on Thursday afternoon in Sanders Theatre. Together with the Past Presidents and present officers of the Society, and with some of the elder members of the Society and with the Local Committee, the delegates of eight scientific societies sat on the stage: in their conspicuous position they were severely tried by the sultry heat, for which ordeal the apologies of the Society are due and herewith tendered. President Loomis opened the session with felicitous words, and called then upon the eight delegates to present the messages of their Societies: the American Philosophical Society (A. B. Hastings), the National Academy of Sciences (F. O. Schmitt), the Physical Society, London (W. B. Mann), the Netherlands Physical Society (J. de Boer), the Japanese Physical Society (H. Yukawa), the American Mathematical Society (Hassler Whitney), the American Chemical Society (G. B. Kistiakowsky), the American Institute of Physics and its Founder Societies (G. R. Harrison). The President then read the messages of the following Societies: the Physical Societies of Denmark, Finland, France, Sweden, and Switzerland; the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Society of Mechanical Engineers, the Institute of the Aeronautical Sciences, the Institute of Radio Engineers, Sigma Pi Sigma; and personal messages from Niels Bohr and Max von Laue. Messages from the five German physical societies and from the American Institute of Mining and Metallurgical Engineers arrived too late for reading, but will be preserved in the archives of the Society. After these greetings were communicated to the audience, G. B. Pegram spoke on the early years of the Society, G. F. Hull, Sr., on some of its early meetings, and K. K. Darrow on the recent years of the Society.

On Friday morning in Sanders Theatre was held a General Session comprising addresses by E. U. Condon on the development of American physics, by C. G. Suits on physics in industry, and by President F. W. Loomis on the future of physics.

On Friday afternoon in Sanders Theatre the Chairmen of our four Divisions spoke on their respective fields. These Chairmen are Louis Malter (Division of Electron Physics), J. W. Liska (Division of High-Polymer Physics), William Shockley (Division of Solid-State Physics), and H. L. Dryden (Division of Fluid Dynamics). They were followed by J. S. Foster who reviewed the story of physics in Canada.

Invited papers on the general programme were given by Howard Aiken, E. O. Hulburt, R. A. Millikan, Julian Schwinger, M. S. Vallarta, and E. Bright Wilson, Vallarta speaking as representative of Mexico. A Symposium on linear accelerators consisted of three papers by Wolfgang Panofsky, R. F. Post, and J. C. Slater. A Symposium was held throughout Saturday by our Division of Electron Physics. The titles of all of these papers are given hereinafter.

The banquet of the Society was held on the Friday evening in the Ballroom of the Continental Hotel. With President Loomis twelve Past Presidents of the American Physical Society sat at the Speakers' Table: they were Henry Crew (President in 1909 and 1910), R. A. Millikan (1916 and 1917), K. T. Compton (1927 and 1928), W. F. G. Swann (1931 and 1932), P. D. Foote (1933), H. M. Randall (1937), John Zeleny (1940), G. B. Pegram (1941), P. W. Bridgman (1942), A. W. Hull (1943), Harvey Fletcher (1945), and E. U. Condon (1946). All spoke, too briefly. No such gathering of notable

physicists at one table has been seen in our time, perhaps no other will be seen before our Centennial. Especial gratitude is due to Henry Crew, who at the age of ninety made the long journey from Evanston to take part in this meeting, and evoked before the audience his memories of Helmholtz and Kirchhoff, Brace and Rowland from 1883. It is no pleasure to record that fewer than two hundred attended this unique banquet. In general, too few by far of our members feel the obligation to be present at what, in these days of simultaneous sessions, is normally the only function of our meetings at which all can be together.

The Society has lost through death, according to reports reaching this office, A. E. Bowen (Red Bank, New Jersey), J. P. Cooley (Palisades, New York), P. F. Hammond (University of Wyoming), W. W. Hansen (F, Stanford University), J. K. L. MacDonald (Inyokern), and J. A. Vargus (Inyokern), the last two having died in an airplane crash while on their way to our Berkeley meeting.

The Council met on Thursday morning.

Elected to Fellowship: Ernst Billig, W. L. Bond, J. R. Haynes, E. A. Hiedemann, A. V. Hollenberg, Vivian A. Johnson, Thomas Lauritsen, M. B. Sampson, L. R. Walker, R. G. Wilkinson, and Chien-Shiung Wu.

Elected to Membership: Elihu Abrahams, Bruce L. Adams, Harold R. Allan, Casper J. Aronson, Raphael F. Aronson, Benjamin L. Averbach, William W. Balwanz, Murray L. Barasch, Peter T. Barrett, Joe R. Beeler Jr., John Tyers Beher, Pasquale Bencivenga, Leon Bess, George H. Best, Egil K. Bjornerud, Richard C. Bradley, Ernest C. Briggs, Jr., Arthur S. Brill, Nicholas E. Broderick, Paul Brodt, Daniel P. Brooks, Robert J. Brousseau, Albert Brown, André Bruaux, John H. Bryant, David S. Bunbury, Charles Patrick Cadenhead, Edward W. Cannon, Richard R. Carlson, Edward F. Carr, William W. Carter, William R. Champion, Edwin J. Chernosky, Henry Chessin, H. N. Clarkson, Clarence M. Connelly, William A. Conrad, James E. Corry, Jr., Christopher Dean, Hervasio G. De Carvalho, Joseph J. Devaney, S. S. Dharmatti, Vernon H. Dibeler, Margarete Ehrlich, Richard W. Fink, Charles B. Fisk, Siegfried W. Fluegge, Stephen G. Gasiorowicz, R. E. Gibson, William S. Gilbert, Paul W. Gilles, John P. Gould, Howard Greenberg, Alan Adams Grometstein, Manfred Grunberg, Robert N. H. Haslam, Edward D. Havens, Jr., Charles H. Heuer, Richard J. Hirsch, Sidney Hoffman, Norman H. Horowitz, Howard S. Jarrett, Betsy M. Jones, Byron E. Keene, *William D. Kennedy, Geoffrey Knight, Jr., Jonathan H. Knox, Eli Kogos, John Kostolos, Jr., Walter H. Kruschwitz, James E. Kupperian, Jr., Dieter Kurath, Benjamin Lax, Daniel Leenov, Wayne Lowry Lees, Rannzo Leo, Stanley L. Leonard, John C. Lindsay, Ralph Livingston, Hans Walter Loeb, Harvey I. Lundy, Geraldean L. Lynn, Esteban F. R. Manfredi, Marvin Masel, Edward A. Mason, Frank D. Mason, Kurt L. Mayer, Benjamin T. McClure, Dale J. Meier, C. Howard Mellor, Harold W. Miller, Henry Thomas Minden, George R. Mitchell, George Davies Monk, C. Frank Mooney, Walter J. Moore, Cecile Morette, F. Hayder Morgan, Russell H. Morgan, Peter A. Morris, Mark P. Morse, Jr., Philip M. Mostov, Raymond J. Munick, Charles A. Murison, William Frederick Nash, John H. Neiler, Roger Newman, Richard Edwin Norberg, Carlos Obregon, Jack E. Oliver, Akshayabat Pande, Kenneth John Parry, Maynard D. Pearson, Robert H. Penfield, Sam R. Peoples, Earl M. Pollock, Charles E. Porter, Jr., Dwight C. Pound, Jerome Pressman, Wolfgang Ramm, Robert B. Raphael, Haskell A. Reich, Howard M. Robbins, Donald Murray Roberts, Fred W. Roberts, Robert C. Rohr, David Rosenfeld, Norbert Rosenzweig, Bernd Ross, Steven W. Ross, Wallace R. Rushin, Irving Sacks, Paul G. Saper, Matrala L. N. Sastri, William F. Schreiber, James F. Sears, Howard H. Seliger, David Shansky, Elmer M. Sharp, Joseph Silverman, Robert L. Small, Albert E. Smith, Joseph Sperrazza, Gordon L. Squires, Philip L. Stocklin, Ralph E. Sturm, John G. Teasdale, Walter F. Titus, Albert B. Tonik, Otto C. Turchan, Edwin M. Vahghn, Charles E. Van Albert, William M. Visscher, Garvin L. Von Eschen, Arthur A. Vuylsteke, Sidney Walovnick, William E. Water, Jr., Otto A. Weinreich, Eric A. Weiss, Wilfrid B. Whalley, Herman H. Wieder, Robert Lee Wild, Robert R. Williamson, Harvey Winston, Robert J. Wohl, Hiroshi Yamauchi, Paul M. Yavorsky, Myron Youdin Arnold Zellner, and Elmer L. Zimmerman.

* This man appeared on the Washington Agenda, but his second sponsor was not a member and he was not elected.

The Tellers have reported that the two Amendments to the Constitution of the American Physical Society submitted to the membership last February were carried by large majorities. Their texts will appear in a later issue of the Bulletin.

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

Ceremonial Session

Opening words by F. W. LOOMIS, *University of Illinois.*

Messages of greeting and felicitation from foreign and American scientific societies (listed elsewhere in these Minutes).

The early years of the American Physical Society. G. B. PEGRAM, *Columbia University.*

Early meetings of the American Physical Society. G. F. HULL, SR., *Dartmouth College.*

The recent years of the American Physical Society. K. K. DARROW, *Bell Telephone Laboratories.*

General Session

The development of American physics. E. U. CONDON, *National Bureau of Standards.*

Physics in industry. C. G. SUITS, *General Electric Company.*

The future of physics. F. W. LOOMIS, *University of Illinois.*

Speeches by the Chairmen of the Four Divisions

LOUIS MALTER, *RCA Laboratories* (Division of Electron Physics).

J. W. LISKA, *Firestone Tire and Rubber Company* (Division of High-Polymer Physics).

WILLIAM SHOCKLEY, *Bell Telephone Laboratories* (Division of Solid-State Physics).

H. L. DRYDEN, *National Advisory Committee for Aeronautics* (Division of Fluid Dynamics).

Symposium on Linear Accelerators

WOLFGANG PANOFSKY, *University of California, Berkeley.*

R. F. POST, *Stanford University.*

J. C. SLATER, *Massachusetts Institute of Technology.*

Other Invited Papers

The uses of computing machines. HOWARD AIKEN, *Harvard University.*

The light of the night sky. E. O. HULBURT, *Naval Research Laboratory.*

Recollections of the American Physical Society. R. A. MILLIKAN, *California Institute of Technology.*

Quantum electrodynamics. JULIAN SCHWINGER, *Harvard University.*

The sun and cosmic rays. M. S. VALLARTA, *University of Mexico.*

Molecular spectroscopy and molecular structure. E. BRIGHT WILSON, *Harvard University.*

Symposium of the Division of Electron Physics

Studies of electrons in gases by high frequency techniques. SANBORN C. BROWN, *M.I.T.*

Ionospheric measurements employing a voltage-scanning probe. W. G. DOW, *University of Michigan.*

The Townsend discharge on a micro-second time-scale. J. A. HORNBECK, *Bell Telephone Laboratories.*

Space-charge effects in electron beams and their reduction by positive-ion trapping. E. G. LINDER AND K. G. HERNQVIST, *R.C.A.*

Recent experimental results and theoretical interpretations on ionic phosphors. F. E. WILLIAMS, *General Electric.*

Studies of thermionic emission, photoelectric emission and conductivity of oxide-coated cathodes. W. B. NOTTINGHAM, *M.I.T.*

Photoelectric studies on the energy structure of barium oxide. L. APKER, E. TAFT, AND J. DICKEY, *General Electric.*

Deflection defocusing in cathode-ray tubes and methods for correction. R. G. E. HUTTER, L. H. MCKEE, AND S. W. HARRISON, *Sylvania.*

Beta-Ray Emitters; Nuclear Apparatus

A1. Radioactive Materials as X-Ray Sources. H. F. GUNLOCK, *Ohio State University.*—X-rays resulting from orbital capture or from internal conversion identify, by their wave-length, the radioactive element emitting them and the particular electronic levels involved. Various means for determining the wave-length are discussed and their use is illustrated in the study of the decay schemes of Pd^{103} and the Rh^{103} isomer. Examples of the use of x-ray emitting material as a source in radiography are given.

A2. The Effect of C^{14}, Ca^{45}, P^{32}, I^{131}, and Zn^{65} on Photographic Emulsions.* DANIEL STEINBERG** AND A. K. SOLOMON, *Harvard Medical School.*—The density response of photographic emulsions to five biologically important radioisotopes has been determined (C^{14}, Ca^{45}, P^{32}, I^{131}, and Zn^{65}). A set of eight sources of graded intensity was prepared for each isotope, and commercially available films (Eastman No-screen x-ray film, Type M stripping film, Type K industrial x-ray film, and NTB stripping film) were exposed for measured intervals to the eight sources. Exposure-density curves are presented, exposure being expressed in terms of total atomic disintegrations per square centimeter of film during the period of film source contact. Sensitivity and contrast are presented for each emulsion isotope combination in the form of characteristic curves. Photographic effectiveness is observed to decrease with increasing maximum energy of the radiation of the isotope. However, no simple quantitative correlation is observed between sensitivity and E_{max}. The reciprocity law has been checked in the case of Zn^{65} for exposures varying from 1 to 200 hours and found valid (Type M stripping film).

$\log_{10}$ exposure at density 0.1 above background.

Film	C^{14}	Ca^{45}	I^{131}	P^{32}	Zn^{65}
Eastman No-screen x-ray	6.16	6.42	6.70	7.11	7.96
Eastman Type M stripping	7.39	7.84	8.35	8.75	9.47

* This work has been supported in part by the ONR and the AEC.
** Postdoctorate Fellow, National Institute of Health.

A3. On the Excited States of Li^7.* MICHEL TER-POGOSSIAN, J. EUGENE ROBINSON, AND HAROLD GODDARD, *Washington University.* (Introduced by A. L. Hughes.)—In a recent unpublished note, H. Primakoff and E. Feenberg suggested the possibility of the existence of two closely spaced excited states in Li^7. This hypothesis appears necessary because of the selection rules in the Be^7 decay and the $B^{10}(n, \alpha)Li^{7*}$ reaction. The first step made to test this hypothesis was to compare the energies of the γ-radiations emitted in the transitions $Li^{7*} \rightarrow Li^7$ for different methods of producing Li^{7*}. The energy of the γ-radiation emitted after the K capture in Be^7 was carefully compared, in a high resolution beta-ray spectrometer, with the energy of the γ-radiation emitted by Au-198 (energy accurately measured by DuMond and his group). This comparison gave the energy of 478.6 ± 0.5 kev. This value is very close to the energy obtained by Elliott and Bell (478.5 ± 1.5 kev) for the gamma-radiation following the (n, α) reaction on B-10, using the same Au comparison line. If these two excited states of Li^7 are different they are not separated by more than 2 kev.

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

A4. K Capture of Be^7 and the Excited State of Li^7.* R. M. WILLIAMSON AND H. T. RICHARDS, *University of Wisconsin.*—The fraction of Be^7 K capture to the 478 kev excited state of Li^7 has been experimentally determined to be 0.107 ± 0.02. The experimental method consisted in measuring the number of Be^7 atoms by counting neutrons from the $Li^7(p, n)Be^7$ reaction, and in observing the subsequent number of 478 kev gammas by use of a counter calibrated by beta-gamma coincidences from Au^{198}. Implications concerning the character of the 478 kev Li^7 level are discussed.

* This work was supported in part by the Wisconsin Alumni Research Foundation and in part by the AEC.

A5. Disintegration Energy of Al^{29}.* L. SEIDLITZ, E. BLEULER, AND D. J. TENDAM, *Purdue University.*—A discussion by Barkas[1] shows that the mass difference between Al^{28} and Si^{28} is about 1.5 Mev higher than expected from the decay energies of adjacent nuclei with the same symmetry (Na^{24}, $F^{20} \cdots$, P^{32}, $Cl^{36} \cdots$). If this is due to the closure of a shell for Si^{28}, a similar anomaly might be expected for the transition $Al^{29} - Si^{29}$ ($T_{\frac{1}{2}} = 6.6$ min.). Al^{29} was produced by bombarding Mg with the α-particles of the Purdue cyclotron. Absorption and coincidence measurements show a β^--spectrum of 2.4 Mev upper limit, accompanied by γ-radiation in cascade. Indications of a partial β^--spectrum of lower energy and of a cascade of γ-rays are present. Tentative decay schemes yield a total disintegration energy between 3 and 3.5 Mev. The comparison of the decay energies of corresponding nuclei (Ne^{23} 4.3, Na^{25} 3.7, Mg^{27} 2.64, Al^{29} 3–3.5, Si^{31} 1.8, P^{33} ?, S^{35} 0.167 Mev) indicates a similar anomaly in the mass difference $Al^{29} - Si^{29}$ as found for $Al^{28} - Si^{28}$.

* Supported by the ONR.
[1] W. H. Barkas, Phys. Rev. 72, 346 (1947).

A6. The Forbidden Beta-Spectra of Sr^{89}, Sr^{90}, and Y^{90}. F. B. SHULL, C. H. BRADEN, AND L. SLACK, *Washington University.*—The spectrum "shape" for a forbidden beta-transition cannot be uniquely predicted except in special cases where restricted selection rules are satisfied. Konopinski and Uhlenbeck[1] have shown that one such special transition involves a

spin change of 2 units and a change of parity, provided Gamow-Teller rules govern the beta process. The expected distribution differs from that for an allowed transition by a factor $G\sim(W_0-W)^2+(W^2-1)$. Changes of parity for the beta-transitions of Sr^{89}, Sr^{90}, and Y^{90} are expected on the basis of the nuclear shell model.[2] In view of the *ft* values, these are first-forbidden by G-T rules, and the relatively large magnitude of $(W_0^2-1)ft$ in each instance favors a spin change of 2 units.[2,3] All three spectra have been measured in a double-focusing spectrometer. When analyzed as "allowed" Fermi-Kurie plots, all three display the characteristic upward bulge introduced by the factor G for energies above $W_0/2$. When analyzed as "forbidden" FK plots (i.e., after G is divided out), all three are satisfyingly straight.

[1] E. J. Konopinski and G. E. Uhlenbeck, Phys. Rev. **60**, 308 (1941).
[2] E. Feenberg and K. C. Hammack, Phys. Rev. (in press).
[3] F. B. Shull and E. Feenberg, Phys. Rev. (in press).

A7. The Forbidden Beta-Spectra of Sr^{89} and Y^{90}. H. Clay Price, Jr. and Lawrence M. Langer, *Indiana University.*—Because of the remarkable agreement between theory and experiment found recently[1] in the forbidden beta-transition of Y^{89}, it was thought desirable to examine the spectrum of Sr^{89}. This transition, in spite of its large comparative half-life, is also predicted by the nuclear shell structure analysis[2] to be once forbidden with a spin change of two units and parity change. The source, obtained from Oak Ridge, had in addition to the Sr^{89}, an activity of about 5 percent due to Sr^{90} in secular equilibrium with Y^{90}. Spectra were obtained with and without chemical extraction of the Y^{90}. Measurements were made in the high resolution 40 cm radius of curvature spectrometer with a source of about 0.01 mg/cm² average thickness. It is found that both Sr^{89} and Y^{90} yield forbidden spectra whose shapes are accounted for by the factor $a\sim[W^2-1+(W_0-W)^2]$. This indicates that according to Gamow-Teller selection rules both transitions are indeed once forbidden with parity change and spin change of 2, in agreement with the predictions of the shell model. The end points are: Sr^{89}, 1.463 ± 0.005 Mev; Y^{90}, 2.180 ± 0.008 Mev. This work has been assisted by a grant from the Frederick Gardner Cottrell Fund of the Research Corporation and by the joint program of ONR and AEC.

[1] Lawrence M. Langer and H. Clay Price, Jr., Phys. Rev. **75**, 1109 (1949).
[2] E. Feenberg and K. C. Hammack, private communication.

A8. The Beta-Spectrum of Silver-110. Werner S. Emmerich and J. D. Kurbatov, *Ohio State University.*—The disintegration of Ag 110 into the isobars Cd 110 and Pd 110 was studied in a Wilson cloud chamber. Purified Ag 110 of high specific activity was mounted in the center of the chamber on very thin Zapon film, and pictures of tracks were taken in air and in helium at atmospheric pressures in magnetic fields of 372.5 and 149 gauss. A Kurie plot produced a straight line in the range of 150 to 550 kev indicating the presence of a continuous electron spectrum with an upper energy limit of 0.59 Mev. Upon subtraction of the theoretical component of this spectrum and recalculation of the remainder, evidence was obtained for the existence of a second continuous spectrum with an upper energy limit of 90 ± 10 kev. The intensities of the two continuous spectra were found to be of the same order of magnitude which indicates, considering the careful mounting of the source, that the low energy spectrum is not due to back scattering. The presence of converted electron groups of 0.1, 0.6, 0.9, 1.2, and 1.5 Mev was observed. Monochromatic groups near 0.3 Mev were not well defined. Several single positrons and pairs were found. However, the number of positrons, for which pairs could not be established, did not exceed 0.2 percent of the observed electrons of the beta-spectra.

A9. Radioactive Tin 111. R. A. Hinshaw, *Muskingum College.*—A radioactive isotope of a half-life of 35.0 ± 0.5 minutes has been found in the tin fraction of cadmium bombarded in the cyclotron with 20 Mev alpha-particles.* Using electromagnetically enriched cadmium** the assignment can be made to Sn 111. Positrons of 1.45 Mev and x-rays are observed.

* Acknowledgment is gratefully made for support received from the Ohio State University Development Fund and the Graduate School.
** Supplied by the Y-12 plant, Carbide and Carbon Corporation through the Isotopes Division, USAEC, Oak Ridge, Tennessee.

A10. Radiations from Indium (114) and Barium (140).* C. E. Mandeville and E. Shapiro, *Bartol Research Foundation.*—The 72-second In^{114} activity, in equilibrium with its 48-day isomeric parent, was induced in metallic indium irradiated by slow neutrons in the Oak Ridge pile. Chemical separations were performed for the removal of Ag, Ca, Cu, Fe, Ni, and Pb as possible impurities. The beta-rays have a maximum energy of 1.89 Mev as measured by aluminum absorption, and the maximum gamma-ray energy is 0.90 Mev as determined by coincidence absorption. A lead absorption curve gives quantum energies of 0.15 Mev and 0.70 Mev. Beta-gamma coincidence data show that the harder gamma-rays are associated with less than 5 percent of the nuclear beta-rays. A gamma-gamma-coincidence rate of 0.25×10^{-3} coincidence per gamma-ray was noted. Fission-produced Ba^{140} emits beta-rays of maximum energy 0.91 Mev. Lead absorption curves observed continuously for 90 hours during growth of La^{140} reveal the presence of 0.14 Mev and 0.6 Mev quanta emitted by Ba^{140}. Beta-gamma coincidence measurements show that the beta-spectrum of Ba^{140} is complex.

* Assisted by the joint program of ONR and AEC.

A11. Studies on Synthetic LiF as a Scintillation Detector of Heavy Particles and Quanta. E. C. Farmer, H. B. Moore, and Clark Goodman, *Massachusetts Institute of Technology.**—Studies have been made on synthetic LiF as a scintillation detector of heavy particles and quanta, particularly in view of its possibility as a high efficiency detector of thermal neutrons. Most of the results reported were obtained with a crystal of LiF grown in vacuum. Measurements were taken with the crystal, photomultiplier tube (1P28) and paraffin block cooled with solid CO_2, using three different sources: a Co^{60} gamma-source, a Po-Be neutron source and a Po alpha-source. The results for thermal neutrons were obtained by difference, with and without a boron shield around the crystal. Calculations from counting rate extrapolated to zero pulse height give an efficiency of 9.5 percent for thermal neutrons, 11 percent for Po α's and 1.6 percent for Co^{60} gammas. The duration of the light pulse from LiF is $\leq1\mu$sec. with no noticeable "after" pulses. Comparison runs were made on the three types of synthetic LiF (vacuum, ammonia, and air grown) using the alpha- and gamma-sources. Because of differences in size, relative efficiencies for the different type crystals were not attempted; however, there does not seem to be any marked difference between them.

* This is a joint undertaking of M.I.T. and ONR.

A12. Ring Focus in a Thin Magnetic Lens Beta-Ray Spectrometer. Joseph M. Keller, Ernest Koenigsberg, and Arthur Paskin, *Iowa State College.*—Various writers[1] have suggested an improvement in resolution of a magnetic lens type beta-ray spectrometer if a suitably located annular orifice is used for momentum discrimination. Primarily to study the application of "ring focus" selection to a thin lens spectrometer, we have calculated the electron trajectories for the Iowa State College spectrometer.[2] The differential equation of the orbit, for zero angular momentum about the symmetry axis, was integrated numerically on International Business Machines to yield a set of trajectories starting from a point source on the axis. For a fixed range of initial electron directions, different positions of ring focus occur (all at nearly the same

radius) for different values of electron momentum per unit magnetizing current. The calculated trajectories are used to predict line shapes. Effects of a finite source diameter and of finite angular momenta are estimated by perturbation methods.

* This work was supported by AEC.
[1] C. M. Witcher, Phys. Rev. **60**, 32 (1941); S. Frankel, Phys. Rev. **73**, 804 (1948).
[2] E. N. Jensen, L. J. Laslett, and W. W. Pratt, Phys. Rev. **75**, 458 (1949).

A13. Constant Sensitivity Gamma-Ray Detector.* J. PINE AND R. SHERR, *Princeton University*.—For many experiments it would be desirable to use a gamma-ray detector whose sensitivity is independent of energy. The scintillation counter offers this possibility. The larger absorption of softer radiation is compensated for by the smaller average pulses so that the bias curves for different energies might cross at some small bias. Accordingly, anthracene and NaI were investigated. Absolute efficiencies were obtained by comparison with a copper Geiger counter. The integral bias curves did not cross and the efficiencies exceeded the theoretical values at low bias. The latter effect has been reported by Hofstadter and is presumably due to radiation scattered into the detector. The absence of cross-over in the integral bias curves may also be caused by this effect. However, the differential bias curves for a single NaI crystal were found to cross at a particular bias which was far removed from the region of excessive efficiency. For our arrangement a 5-volt single channel discriminator would give an efficiency of detection of 1.1 percent for energies between 0.510 and 1.24 Mev. Preliminary measurements indicate the same efficiency for 1.8 Mev radiation.

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

A14. A Micro Calorimeter Suitable for Study of Easily Absorbed Nuclear Radiations.* C. V. CANNON** AND G. H. JENKS, *Oak Ridge National Laboratory*.—A calorimeter, which can be applied to the measurement of radio-active decay energies when easily absorbed radiations are involved, has been designed and constructed. The calorimeter is of an isothermal type, operating at the temperature of liquid nitrogen and using the rate of vaporization of nitrogen, under constant pressure, as a measure of the heat input. Calibration of the calorimeter was carried out by means of a resistance heater. The sensitivity of the calorimeter is such that heat inputs as low as 7×10^{-6} cal./sec. can be measured with an accuracy of 1 percent. Reference is made to the application of the calorimeter to the study of the decay of P^{32} [1] and of tritium.[2]

[1] Zumwalt, Cannon, Jenks, Peacock, and Gunning, Science **107**, 47 (1948).
[2] Jenks, Ghormley, and Sweeton, Phys. Rev. **75**, 701 (1949).
* This document is based on work performed under contract for AEC.
** Present address: Department of Physics, University of Washington, Seattle, Washington.

Papers Not Classed Elsewhere

B1. Collimation Error in Small Angle X-Ray Scattering. K. L. YUDOWITCH, *Florida State University*.—It has been indicated[1] in small angle x-ray scattering experiments that excessive collimation error may be introduced by the use of an incident beam of finite cross section. To account for this error the usual procedure[2] has been multiple integrations for rays reaching a single point on the film from any position along the width or height of each slit. However, the common effect from both a finite slit width and height and a skew incident beam is a range of scattering angle ($\delta\epsilon$). The multiple integrations over each slit dimension are thus reduced to a single integration over scattering angle, which entails first finding the limits of scattering angle. The assumption of a constant distribution of intensity throughout the range, allows $\delta\epsilon$ to be taken as a measure of the collimation error. Minimization of $\delta\epsilon$ then leads to a quartic equation whose solution yields optimum values of slit height-to-width ratio or eccentricity. Determination of this optimum slit eccentricity is prerequisite to best results in small angle x-ray scattering.

[1] K. L. Yudowitch, J. App. Phys. **20**, 174 (1949).
[2] C. G. Shull and L. C. Roess, J. App. Phys. **18**, 295 (1949).

B2. Design of Small, Self-quenching, G-M Counters. C. V. ROBINSON, *Harvard Medical School*.—Several small self-quenching G-M counters have been constructed recently by the author for use in medical research. The diameters are in the range from 2 to 6 mm and the mixtures consist of argon and ether* or argon and ethyl acetate. The research connected with the design of these counters will be discussed and details of construction shown.

* C. V. Robinson and R. E. Peterson, Rev. Sci. Inst. **19**, 911 (1948).

B3. An Extension of a Theory of Magnetic Amplifiers. ROBERT T. BEYER AND MING-YI WEI, *Brown University*.—A theory of operation of certain magnetic amplifiers, previously presented,[1] has been extended, in the case of secondaries with infinite a.c. impedance to be valid for large input currents. The second harmonic output is shown to deviate from linearity and pass through a maximum as the direct current is increased. Some experimental evidence is given to support the calculations. The influence of a third harmonic term in the primary current (which has hitherto been considered as a pure sine wave), has also been investigated. It is shown that for small input currents no serious error is introduced by neglecting the higher harmonic.

[1] J. A. Krumhansl and R. T. Beyer, J. App. Phys. **20**, 432 (1949).

B4. Influence of Molecular Structure of Lubricant on the Variation of Incremental Friction Coefficient with Speed. J. T. BURWELL AND C. D. STRANG, *Massachusetts Institute of Technology*.—The incremental friction coefficient, defined as $\Delta F/\Delta W$ rather than F/W, where F is the friction force and W the applied load was shown in a previous paper[1] to be independent of all fluid viscous effects. Its variation with speed is found to be characteristic of the lubricant for various types of straight long-chain lubricant molecules. With non-polar hydrocarbon molecules it is found to decrease over the whole range of speed from 0.100 cm/sec. to 75.7 cm/sec. For various straight-chain polar molecules such as fatty acids, esters, metal soaps and alcohols the coefficient is independent of speed at the low end of the range but decreases at the higher speeds. For a series of normal alcohols the coefficient at any speed decreases with chain length up to dodecanol after which it is constant. The similarity is noted between the shape of the friction *vs.* speed curve and that of the curve of structural viscosity *vs.* rate of shear curve predicted by Umstätter[2] on the basis of Maxwell's relaxation relation. Hence, the decrease of this friction coefficient with speed may be due to a shear-induced orientation in the molecular monolayers of lubricant on the rubbing surfaces.

[1] J. T. Burwell and C. D. Strang: J. App. Phys. **20**, 79 (1949).
[2] H. Umstätter, Die Technik, **1**, 46 (1946); Koll. Zeits., **103**, 7 (1943).

B5. The Propagation Modes of a Helix.* WILLIAM SOLLFREY, *New York University*.—Previous researches on the helix have made simplifying approximations about the nature of the boundary conditions. In this paper the field equations and boundary conditions are formulated exactly. They are then solved by an expansion in powers of the ratio of the thickness of the wire to the distance between turns. The method used consists of introducing a new coordinate system, which is such that a helical wire of circular cross-section is a surface in which one coordinate is constant. Maxwell's equations and the electromagnetic boundary conditions are expressed in terms of this system. Since non-orthogonal coordinates are involved, the equations cannot be solved exactly, but a perturbation procedure may be applied as indicated above.

The result of the analysis is to show that there is a principal mode, which propagates with the free space velocity of light in the direction of the wire. The characteristics of this mode are studied, and they are compared successfully with experiment.

* This research was performed under the sponsorship of the Watson Laboratories of the U. S. Air Force under contract with New York University.

B6. Application of a Variational Principle to Biconical Antennas.* C. T. TAI, *Harvard University.*—A theoretical examination is made of the impedance of a biconical antenna, based upon a variational method due to Schwinger. In the present analysis, an integral equation to determine the aperture field is first obtained by matching the tangential electric and magnetic fields along the boundary sphere. Using this integral equation, the effective terminating admittance of the antenna can be expressed in a form that is stationary with respect to small variations in the aperture field. It is shown that the zeroth-order solution of the admittance function thus obtained is the same as the one that Smith derived by neglecting all the high order waves in the interior region except the principal mode. For small-angle cones, the present formulation yields the same exact solution obtained previously, based upon several different methods. The paper also contains a discussion of the first-order approximate solution which is applicable to both small- and wide-angle cones. The analysis includes a discussion of the Ritz method to determine very accurately the characteristic values and characteristic functions for a given cone.

* Supported by ONR.

B7. Terminal Impedance and Generalized Two-Wire Line Theory. K. TOMIYASU AND RONOLD KING, *Harvard University.*—Conventional transmission line theory takes no account of variations in the parameters of the line and of coupling near a terminating impedor or near any change in its uniform properties. A general theory is derived which substitutes for these effects a simple terminal zone network of lumped series and shunt elements which may be evaluated for each type of termination or discontinuity. The apparent terminal impedance, Z_{sa} (which is the impedance actually measured on a lossless line at one-half wave-length from the termination) consists of this network in combination with the theoretical, isolated impedance, Z_s, of the load. Application of the theory to terminations consisting of an open end, a bridge end, a line continuing at an angle, and antennas oriented in the plane of the line and in the plane perpendicular to the line, is outlined.

B8. Jacobian Thermodynamics. F. H. CRAWFORD, *Williams College.*—The author has discussed the utility of Jacobians in thermodynamic theory.[1] The results have been extended to the case of n-variable systems where it is necessary to divide all possible systems into: (a) *unrestricted* and (b) restricted systems (i.e., those having certain variables of limited functional dependence). In either case Clausius' equation $dU=TdS+dW$ is the starting point, with dW expressed as $(n-1)$ separate work terms of the form $Fd\theta$. This gives $2n$ variables on the right, where in case (a), *any* n may be taken as independent. If we set up the Jacobian, J_0, of the remaining n dependent variables with respect to the independent set, according to certain simple rules, then J_0 is a determinant of n^2 derivatives, *symmetric* about the main diagonal. The symmetry is a very concise expression of the general Maxwell relations and means that J_0 contains the $n(n+1)/2$ independent derivatives adequate for a complete thermodynamic discussion. In case (b), certain derivatives will vanish, alone if in the main diagonal, otherwise in pairs; hence a fewer number of derivatives must be measured experimentally to enable others to be determined.

[1] Phys. Rev. 72, 521A (1947); Am. J. Phys. 17, 1–5 (1948); Proc. Am. Acad. (in press).

B9. The Temperature Distribution in an Accreting Medium Containing a Source of Heat. A. E. BENFIELD, *Harvard University.*—Using the mathematical theory of the conduction of heat in solids, the temperature (as a function of distance and time) is calculated for an accreting semi-infinite medium which contains a uniformly distributed source of heat. The medium is initially all at a uniform temperature; the free surface of the medium, at which accretion occurs at a steady velocity v, is held at this initial uniform temperature, while the temperature in the interior of the medium increases due to the heat which is being generated there at the constant rate of A heat units per unit time per unit volume. It is found that, as time goes on, the temperature gradient approaches a steady value, $A/c\rho v$, where c is the specific heat of the medium and ρ is its density. The solution of the problem involves a Laplace transform that is not tabulated in the usual references.[1]

[1] See A. E. Benfield, Quart. App. Math. 6, 4, 439–443 (January, 1949).

Electrical Phenomena in Gases

C1. Afterglow of Nitrogen and Argon in Low-Density Supersonic Streams. THOMAS W. WILLIAMS AND JAMES M. BENSON, *NACA—Langley.*—An investigation will be described in which the phenomena of afterglow were utilized in a way suggested by J. Kaplan to make visible the low density supersonic flows of several gases, including nitrogen, oxygen, air, and argon. Photographs of the afterglow in the flow about wedges will be shown and compared with corresponding schlieren photographs for densities of the stream corresponding to static pressures in the order of 1 mm of mercury. The afterglow is effective in visualizing shock waves and other features of the flow at low densities where it is difficult or impracticable to obtain comparable results with schlieren, shadowgraph, or interferometer methods. The Lewis-Rayleigh afterglow of nitrogen[1,2] in particular is suggested for further use in this way to visualize the supersonic flow in streams having a density sufficiently low for the ratio of Mach number to Reynolds number to be a significant parameter.[3]

[1] S. K. Mitra, Active Nitrogen, a New Theory (Indian Press, Calcutta, 1943).
[2] J. Kaplan, Active Nitrogen, Phys. Rev. 73 No. 5 494–6, March 1, 1948.
[3] Thomas W. Williams and James M. Benson, Preliminary Investigation of the Use of Afterglow for Visualizing Low-Density Compressible Flows, NACA RM No. L9A24a, 1949

C2. Recombination Spectrum and Electron Density Measurements in Neon Afterglows.* R. B. HOLT, J. M. RICHARDSON, B. HOWLAND, AND B. T. MCCLURE, *Harvard University.*—The spectrum emitted by the recombination of positive ions and electrons in the afterglow of a pulsed microwave discharge through neon has been studied as a function of time. Electron density measurements on the plasma were made by the cavity resonant frequency shift method of S. C. Brown and co-workers.[1] The *relative* intensities of several strong lines in the spectrum remains essentially constant during the afterglow, while the *relative* intensities of several others show systematic changes. A recombination coefficient can be calculated on the basis of the observed variation of intensity as a function of time for any individual line, provided that the electron density is measured at some particular time. This technique allows measurements at electron densities much too high to be observed directly by the microwave method. The recombination coefficient obtained for positive ions and electrons in neon varies somewhat with the spectral line and the region of the afterglow chosen for the computation, but is on the order of 10^{-7} cc/ion-sec., in reasonable agreement with the value found at lower electron densities by the microwave method by Brown and co-workers.

* Supported by the ONR.
[1] Massachusetts Institute of Technology, Research Laboratory of Electronics, Technical Report No. 66.

C3. Measurements of Electron-Ion Recombination in Diatomic Gases.* MANFRED A. BIONDI AND SANBORN C. BROWN, *Massachusetts Institute of Technology.*—Previous measurements of recombination coefficients[1] which were made in the monatomic gases have been extended to the diatomic gases H_2, N_2, and O_2. The recombination of electrons with monatomic ions involves the radiation of energy as the process by which a stable combined atom is formed. This process seems to be of secondary importance in the case of recombination of electrons with diatomic ions. This latter recombination evidently is made stable by the absorption of the electron's kinetic energy in vibration and rotation levels of the diatomic molecule. Support of this hypothesis is found in the fact that for electrons and ions of 0.04 e.v. average energy, the recombination coefficient for H_2 is $\alpha=2.5\times10^{-6}$ (ions/cc$-$sec.)$^{-1}$ while for helium the value of α is only 1.7×10^{-8} (ions/cc$-$sec.)$^{-1}$. The variation of α with gas pressure and temperature has been studied.

* This work has been supported in part by the Signal Corps, the Air Materiel Command and ONR.

[1] M. A. Biondi and S. C. Brown, "Measurements of Positive Ion-Electron Recombination"—paper presented at A.P.S. Meeting, Washington, D. C. in April, 1949.

C4. Measurements on the Imprisonment of Resonance Radiation in Mercury Vapor. D. ALPERT, A. O. MCCOUBREY, AND T. HOLSTEIN, *Westinghouse Research Laboratories.*—The rate of escape of imprisoned resonance radiation was determined by measuring the rate at which resonance radiation emerged from a column of mercury vapor after a beam of exciting light was cut off. The emerging scattered light was detected by a photomultiplier and the resulting decay signal displayed on a properly synchronized oscilloscope. Measurements of the decay time, T, were carried out over a range of vapor densities, N, from 3×10^{14} to 2×10^{18} atoms per cc. In the region of Doppler broadening ($N<3\times10^{15}$/cc) the measurements are in good agreement with theory.[1] In the density range between 3×10^{16} and 10^{17}/cc, two time constants were observed. Above this range, the longer decay process, which is perhaps to be attributed to the presence of excited molecules, predominates.

[1] T. Holstein, Phys. Rev. **72**, 1212 (1947).

C5. Self-Broadening of Monatomic Resonance Lines. T. HOLSTEIN, *Westinghouse Research Laboratories.*—The self-broadening of the resonance lines of monatomic gases is treated from the standpoint of the statistical theory of Kuhn and Margenau. In the calculations, explicit account is taken of the degeneracy of excited and ground states. The results apply to the wings of a resonance line, for which the statistical theory should be valid and for which frequency shifts due to binary collisions alone need be considered. One obtains for the spectral distribution a symmetrical "dispersion" expression of the form

$$P(\nu)=\mu[(Ne^2f)/(2\pi m\nu_0)]/(\nu-\nu_0)^2,$$

where N is the density of normal atoms, f the absorption oscillator strength of the line, and μ a dimensionless function of the optical transition involved. In particular, for transitions of the type $(^1S_0-^{1,3}P_1)$, $(^2S_{1/2}-^2P_{1/2})$, and $(^2S_{1/2}-^2P_{3/2})$, μ takes on values 2/9, 1/3, and 0.2561, respectively. The theory is compared with measurements[1,2] on the self-broadening of alkali resonance doublets.

[1] Shang-Yi Ch'en, Phys. Rev. **58**, 884 (1940) (Rubidium).
[2] Chris Gregory, Phys. Rev. **61**, 465 (1942) (Caesium).

C7. A Method for Determining the Average Energy of Electrons in a Gas Discharge.* LAWRENCE J. VARNERIN, JR. AND SANBORN C. BROWN, *Massachusetts Institute of Technology.*—The gas in a resonant cavity will break down when the losses of electrons to the walls are replaced by ionization in the body of the gas. With an a-c field applied, the breakdown depends upon the coefficient of diffusion of electrons, D. If a small d-c sweeping field is applied, it will depend, as well, upon the coefficient of mobility of electrons, μ. Breakdown measurements with d-c fields and without d-c fields applied then permit a determination of the ratio D/μ. This quantity is a direct measure of the average energy of electrons in a gas. It is given, as well, by the ratio of the first Townsend ionization coefficient η, to the a-c ionization coefficient, ζ. Results for helium will be presented.

* This work has been supported in part by the Signal Corps, the Air Materiel Command, and ONR.

C8. High Frequency Breakdown in Magnetic Field.* BENJAMIN LAX AND SANBORN C. BROWN, *Massachusetts Institute of Technology.*—The condition for breakdown in a gas is expressed as a balance between the number of electrons produced by ionization and those lost by diffusion. A magnetic field which is transverse to the applied microwave field has two principal effects upon the electrons in a gas discharge. The energy transferred to the electron between collisions from a constant electric field shows a resonance character whose maximum occurs when the "cyclotron" frequency is equal to r-f frequency. The second effect is a reduction in the diffusion of the electrons to the walls. These effects become more and more significant at lower pressures, resulting in startling reduction of breakdown voltages near resonance. A brief description of the apparatus and the methods used in obtaining the experimental results will be presented. The results observed in air and helium will be shown. The curves for the latter gas are compared with those obtained theoretically.

* This work has been supported in part by the Signal Corps, the Air Materiel Command, and ONR.

C9. Electric Breakdown in CO_2 from Low Pressures to the Liquid State.* D. R. YOUNG, *Massachusetts Institute of Technology.*—Carbon dioxide, with a critical temperature of 31°C, allows the investigation of the change from the gaseous to the liquid type of electric breakdown during a continuous change in the density. Paschen's similarity law has been verified at low pressures. At high pressures, small departures are observed for long gap-lengths and large departures for small gap-lengths. Simultaneously the scatter of the breakdown voltage becomes independent of illumination and the breakdown strength dependent on the cathode material. This seems to be due to the onset of field emission. Measurements of pre-breakdown currents have yielded values for the Townsend first coefficient (α) as well as for the field emission constants. For small gap-lengths the current is higher than predicted by the normal field emission equation, indicating some new process which becomes effective at short gap distances. The transition from gas to the liquid state does not produce a discontinuous change of the breakdown voltage.

* Sponsored by ONR, the Army Signal Corps, and the Air Force under contract N5 ori-07801.

C10. Measurement of Temperatures in Complex Flame Structures by High Resolution Spectroscopy of the Sodium *D*-Lines, I. F. P. BUNDY AND H. M. STRONG, *General Electric Company.*—Sodium atoms in a flame of reasonable thermodynamic equilibrium radiate and absorb as thermally excited oscillators in equilibrium with the flame gases. Therefore, the brightness at any particular wave-length within the intensity contour of a sodium line depends only on the temperature and the emissivity of the flame for that particular wave-length, and the black body brightness is the observed brightness divided by the emissivity. The brightness may be measured by photographic densitometry, and the brightness scale calibrated by use of a standard uniform flame or arc of known temperature. The necessary high resolving power is conveniently at-

tained by use of an interferometer. The emissivity may be determined by comparing the brightness of the mirrored and unmirrored flame or by measurements of the spectral line width. Some of the advantages of the method are that the temperature distribution in a complex flame structure can be mapped from one photograph, the temperatures of submerged zones can be determined with considerable accuracy, and the temperatures of flames hotter than can be matched with conventional comparison lamps can be measured. The method is subject to the usual difficulties of high resolution spectroscopy and photographic densitometry.

C11. Measurement of Temperatures in Complex Flame Structures by High Resolution Spectroscopy of the Sodium *D*-Lines, II. H. M. STRONG AND F. P. BUNDY, *General Electric Company.*—The measurement of flame temperature by the conventional sodium line reversal method does not enable one to analyze the temperature structure in a complex flame or to measure temperatures higher than that of the hottest incandescent comparison radiator obtainable, the carbon arc. This method makes use of the sodium line reversal principle but uses a bright sodium vapor lamp as the comparison radiator. The observation of the match point is made photographically through a Fabry-Perot interferometer instead of the visual low resolving power spectroscope. The sodium lines are then fully resolved. Reversal temperatures can be observed for different parts of the flame structure. The photographs also enable one to measure the absorption by the flame at selected positions on the sodium line contour. The reversal temperatures together with absorption data enable one to compute the temperatures of inner zones of the flame. This method requires the photographic measurement of intensity and is attended by the usual difficulties in measurements of this kind.

Semi-Conductors, Phosphors, Ferroelectricity, Ferromagnetism

D1. Thermionic Emission of (BaSr)O without Metallic Support. GEORGE E. MOORE, *Bell Telephone Laboratories.*—To define problems associated with oxide cathodes, experiments have been performed in this laboratory on systems analogous to the oxide cathode but simpler physically and chemically. D. E. Wooldridge suggested the present experiment intended to eliminate effects associated with support metals, such as interface phenomena and various products of chemical interaction between (BaSr)O and support metal (including impurities); effects often thought responsible for high emission in oxide cathodes. The ideal sought is (Ba Sr)O isolated from foreign metal but in a structure permitting thermionic observations. To achieve this ideal, (Ba Sr)O applied to the outer surface of an internally heated MgO ceramic 1 mm thick, is capacitatively coupled to a Mo electrode inside the MgO and connected to the voltage source. No reaction apparently occurs between MgO and (Ba Sr)O and this structure is believed an approximation to the ideal desired. Although some questions require further investigation, emissions between 3 and 10 ma/cm² at 850°C have been observed in early experiments. Although low relative to the usual oxide cathode, this is enormous compared either to clean refractory metals or to the uncoated ceramic. To avoid charging effects, emission was measured in microsecond pulses using a high gain wide-band amplifier developed by R. W. Hull.

D2. Secondary Emission from Silicon and Germanium Oxides. H. E. MENDENHALL, *Bell Telephone Laboratories.*—Thin films of evaporated silica about 100A thick have been studied as secondary electron emitters. When backed by commercially pure platinum and after heating from 700° to 1000°C, a secondary emission ratio of 4.5 at 500 volts bombarding energy is developed. When backed by pure tantalum that had previously been outgassed to 2000°, the highest δ obtainable was only 1.59 at 650 volts due possibly to the lack of impurity activators. A very pure germanium oxide film sprayed on well outgassed tantalum showed charging of the surface when bombarded at room temperature. The highest δ observed was 1.35 at 500 volts energy at a target temperature of 850°C. Upon heating to 1150°C for over 10 hours the film which was 1 mg/cm² in thickness evaporated off leaving the $\delta=1.31$ at 650 volts at any temperature from room temperature up to 850°C. The crossover voltages for δ equal to unity were now 282 and 2850 close to reported characteristics for clean tantalum. The work was continued with "pure" germanium dioxide backed with commercially pure platinum to obtain a greater supply of activators. After heating to 700° and 850°C for about an hour, secondary emission ratios from 5 to 6 were obtained at about 700 volts bombarding energy.

D3. Electron Injection in *P*-Type Germanium.* RALPH BRAY, *Purdue University.*—Decreases in resistance of *N*-type germanium under high field pulse conditions[1] are apparently due to the injection of holes from the positive contact.[2] To explain similar resistance decreases[1] in *P*-type germanium, the voltage distribution along the sample was determined by probe methods when five microsecond constant current pulses were applied through soldered end contacts. The largest and most rapid resistance changes were found near the negative contact, indicating *that electrons are injected from the negative contact.* Only small negative space charge was measured, indicating that the hole density increases to compensate for increased electron density. Hall effect measurements using high field pulses corroborate the increased electron concentration. Superimposing a transverse magnetic field, *H*, produces magnetoresistive effects which are largest near the positive contact, indicating that *H* decreases the electron penetration depth. This may be due to deflection of the holes and electrons to the same surface, increasing the local concentration there, and hence the recombination rate. A *P*-type transistor was made using negative emitter and positive collector electrodes, in application of the electron injection effect.

* Work supported by Signal Corps.
[1] Ralph Bray, Phys. Rev. **74**, 1218 (1948); Bray, Lark-Horovitz, and Smith **72**, 530 (1947).
[2] E. J. Ryder and W. Shockley, Phys. Rev. **75**, 310 (1949).

D4. The Barrier Layer on *P*-Type Germanium.* H. Y. FAN AND R. BRAY, *Purdue University.*—Surface states on high resistivity *N*-type germanium appear to fix the Fermi level at the surface close to the top of the full band. This produces a *P*-type surface inversion layer, and makes possible a large inward flow of holes in the forward direction.[1] The large increase in conductivity produced by electron injection in *P*-type germanium[2] ($\rho\sim 2$ ohm-cm) with soldered contacts, suggests that in this case the Fermi level at the surface is close to the bottom of the empty band, producing an *N*-type inversion layer. *P*-type rectification and photovoltaic effects[3] have been obtained with certain soft metal whiskers on etched high resistivity samples indicating that also in these cases the Fermi level at the contact is not close to the full band. However tungsten whiskers give poor rectification. According to contact potential measurements by Benzer[1] the Fermi levels at free, etched surfaces of *P*- and *N*-type germanium samples in air lie within 0.1 ev of each other. The barrier layer in *P*-type germanium therefore seems to be influenced by the metal contact.

* Work supported by Signal Corps.
[1] J. Bardeen and W. H. Brattain, Phys. Rev. **75**, 1208 (1949).
[2] Ralph Bray, see companion abstract.
[3] R. Bray and K. Lark-Horovitz, Phys. Rev. **71**, 141 (1947).

D5. The *P*-Type Germanium Transistor. W. G. PFANN AND J. H. SCAFF, *Bell Telephone Laboratories.*—The transistor effect described by Bardeen and Brattain for *n*-type germanium[1] has been found in *p*-type germanium. In the *p*-germanium transistor the emitted carriers are electrons and the collector is biased positively with respect to the base, in contrast to the *n*-type device wherein the carriers are holes and the collector is biased negatively. As in the *n*-germanium transistor amplification of power occurs both by impedance step-up and by current multiplication ($\alpha>1$). *p*-germanium of moderately high resistivity was used. It was produced by the thermal conversion of high back voltage *n*-germanium.[2] Preparation of the germanium surface and electrical forming followed generally procedures described for high back voltage germanium rectifiers.[3] The point-contact electrodes were of phosphor bronze. As compared with the *n*-germanium transistor, α's[1] were lower and cut-off frequencies were higher. The latter may be attributed in part to the fact that the mobility of electrons in germanium is higher than that of holes.

[1] J. Bardeen and W. H. Brattain, Phys. Rev. **74**, 230 (1948).
[2] J. H. Scaff and H. C. Theuerer, NDRC Report 14Sr1408-555, October 24, 1945.
[3] Torrey and Whitmer, *Crystal Rectifiers* (McGraw-Hill Book Company, Inc., New York, 1946).

D6. Electrical Properties of Crystal Grain Boundaries in Germanium. G. L. PEARSON, *Bell Telephone Laboratories.*—As ordinarily prepared high back voltage germanium ingots contain numerous crystals oriented in varied directions. A study of the electrical properties of the grain boundaries in *n*-type material indicate a high localized resistance which shows a reverse saturation characteristic when the applied potential is poled in either direction. When illuminated by a fine spot of light a photo-current is produced which reverses in direction as the light spot is moved across the boundary. The direction is such that electrons flow away from the boundary (holes flow toward the boundary). After the sample has been converted to *p*-type by heat treatment the localized resistance at the grain boundary is gone and the photo-current is that of a homogeneous sample. These data are consistent with the idea that the boundary represents a concentration of acceptor centers. It is possible that these centers are due not to chemical impurities but instead to misfit between the crystals. The presence of such a layer of *p*-type material would account for both the rectifying and photoelectric effects observed when the rest of the material is *n*-type. After conversion to *p*-type, the layer would become a thin region of low resistance which would be difficult to detect.

D7. Modulation of the Resistance of a Germanium Filament by Hole Injection. W. SHOCKLEY, G. L. PEARSON, M. SPARKS, AND W. H. BRATTAIN, *Bell Telephone Laboratories.*—When an emitter point contact to *n*-type germanium operates in the forward direction, a substantial fraction of the current consists of holes. We have been able to determine this fraction and also to measure the lifetime of the holes by injecting holes into a thin filament of germanium having a cross-section of about 0.01 cm$\times$0.01 cm. In addition to the current injected by the emitter near one end of the filament, an additional current flows from end to end sweeping the holes into one end of the filament. The space charge of the holes is compensated by an increased concentration of electrons and the net increase in carriers lowers the resistance of the filament. From measurements of the lowered resistance, the added concentrations of holes and electrons and the individual contributions of holes and electrons to the current can be found. From these measurements we conclude that for several cases the emitter current is more than 90 percent holes and that the hole lifetime is about 0.8 microseconds. The holes probably recombine on the surface and longer lifetimes would be found in larger structures. Filamentary transistors utilizing this resistance modulation have operated with point and $p-n$ junction emitters.

D8. Effect of X-Rays on the Absorption and Luminescence of Alkali Halide Phosphors. JAMES H. SCHULMAN, ROBERT J. GINTHER, CLIFFORD C. KLICK, AND LYLE W. EVANS,* *Naval Research Laboratory.*—Experiments on the effect of x-rays on the luminescence of alkali halide phosphors are reported. Particularly interesting phenomena were found with NaCl:(Pb+Mn) previously shown to be a sensitized luminescent system (excitation peaks, 2500A–2900A; emission peak in orange-red).[1] In addition to *F*-center coloration and a long-lived phosphorescence, *X*-irradiation produces the following changes in phosphor properties: (1) the phosphor no longer is excited by the above mentioned ultraviolet wave-lengths; (2) a grey coloration remains after the *F*-centers are bleached by light; (3) a red luminescence is excited by irradiation into the *F*-band immediately after x-ray treatment. The first two effects are permanent; the last, transitory. Transmission measurements show that x-rays erase the Pb^{+2}-induced ultraviolet absorption band. "Killing" of the original u.v.-excited luminescence is thus due to a change in state of the Pb^{+2} sensitizer, the grey visible absorption indicating this change to be: $Pb^{+2}\rightarrow Pb^{\circ}$. Heating removes the grey coloration and restores the characteristic Pb^{+2} ultraviolet absorption band. Making use of the first two effects above, permanent *X*-radiograms can be obtained on NaCl:(Pb+Mn) screens.

[1] Schulman, Burstein, Evans, Ginther, and White, Bull. Am. Phys. Soc. **24** (No. 4), 25 (1949), paper Q1.
* Present Address: Sylvania Electric Products, Inc. Emporium, Pennsylvania.

D9. Spontaneous Polarization of $BaTiO_3$ Single-Domain Crystals.* W. J. MERZ, *Massachusetts Institute of Technology.*—The spontaneous polarization P of $BaTiO_3$ single-domain crystals was measured as a function of temperature. At the Curie point, P_s increases with decreasing temperature as it does for KH_2PO_4, but much steeper than the Langevin theory predicts. Analogous to the other ferroelectrics one finds the spontaneous polarization and the crystal lattice deformation correlated in that $\Delta a/a$ and $\Delta c/c$ are proportional to P_s^2. This is explained by the fact that the piezoelectric constants d_{31} and d_{33} are zero above the Curie point and proportional to P_s below it. At lower temperatures P_s is smaller than expected, apparently due to antiparallel domains and internal strains. This argument is substantiated by the behavior of the birefringence Δn which is exactly proportional to $\Delta c/c$ but not to P_s^2 in this lower temperature region. At the transition point near 0°C a sudden drop of P_s of about $1/\sqrt{2}$ proves again the assumption that this transition results from a change of the polar axis from [001] to [011]. A further drop of P_s occurs at the −80°C transition when the polar axis changes to [111].

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

D10. Dependence of the Intensity of Magnetization and the Curie Point of Certain Iron Oxides Upon the Ratio of Fe^{++}/Fe^{+++}.* LOUIS R. MAXWELL AND J. SAMUEL SMART, *Naval Ordnance Laboratory,* AND STEPHAN BRUNAUER, *Bureau of Ordnance.*—The saturation intensity of magnetization (I_s) of certain unreduced iron oxide catalysts having variable ratios (γ) of Fe^{++}/Fe^{+++} was measured[1] at room temperature with a High-*H* Permeameter[2] at a maximum applied field of 10,000 Oersteds. Starting at $\gamma=0.352$, I_s was found to increase with increasing γ to a maximum at $\gamma=0.50$, agreeing with the known value for magnetite, and then decrease to a small value of I_s for large γ. Extrapolating back to $\gamma=0$, I_s agrees approximately with the value for cubic Fe_2O_3. The value found for I_s at $\gamma=0.352$ is in agreement with Néel's theory[3] of "ferrimagnetism" as applied to Fe_2O_3 and Fe_3O_4. Curie Point (θ) deter-

minations[4] made at an applied field of 3000 Oersteds for γ from 0.352 to 1.276 showed θ to be constant to within a few degrees and to have the same value as for pure magnetite (about 583°C).

* Work partially supported by ONR.
[1] Measurements of the intensity of magnetization were made at the National Bureau of Standards under the direction of Mr. R. L. Sanford.
[2] The apparatus used is described by R. L. Sanford and E. G. Bennett, J. Res. N.B.S. **26**, January 1941.
[3] Louis Néel, Annales de Physique **3**, 137 (1948).
[4] For the method used see L. R. Maxwell and S. Brunauer, Bull. Am. Phys. Soc. **24** (No. 4), 21 (1949).

D11. Magnetic and Electric Properties of Magnetite Single Crystals.* C. A. DOMENICALI, *Massachusetts Institute of Technology.*—Magnetite, according to previous investigators (Weiss, Verwey and de Boer, Okamura, Li, and others), has a low temperature transition (*ca.* −160°C), in which region its properties change abruptly. The magnetic and electric behavior of natural and synthetic single crystals has been investigated by the author, especially in this transition range. Besides substantiating the earlier findings, a number of additional effects have been observed of which the following seem to be the most interesting: (1) the behavior of the magnetization in the transition region depends upon the magnetic treatment while cooling through the transition, and is different for different crystallographic directions; (2) after cooling through the transition region in zero external magnetic field, all three principal crystallographic directions become difficult to magnetize; (3) Barkhausen experiments for temperatures below the transition show that most of the magnetization may result from domain rotation; (4) there is only a very small Barkhausen effect noticeable in the vicinity of −145°C, where the crystal becomes magnetically isotropic; the noise increases greatly as the transition is approached; and (5) the longitudinal saturation magnetostriction along [111] appears to change upon cooling through the transition.

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

D12. Fringe Fields of Ferromagnetic Domains. L. MARTON AND S. H. LACHENBRUCH, *National Bureau of Standards.*—Experiments have been undertaken to determine quantitatively, by electron optical means, the field emerging from single domain walls in ferromagnetic substances. The method used is the bright-field shadow technique,[1] an outgrowth of the electron optical "Schlieren" method described earlier.[2] A more or less parallel beam of electrons was passed normal to the edge of a single crystal of cobalt.[3] The faces of the crystal intersect at right angles and are oriented at 45° to the beam. Measurements were taken on the shadow patterns so obtained, and the approximate fringe field calculations were based upon certain simplifying assumptions, namely, (1) that the domain boundaries are rectangular, (2) that adjacent domain surfaces have uniformly distributed magnetic properties, (3) that the domain walls have finite thickness. Quantitative values of fringe fields will be reported.

[1] J. App. Phys. **19**, 863 (1948).
[2] Phys. Rev. **73**, 1475 (1948).
[3] Cobalt crystal on loan from Dr. R. M. Bozorth, Bell Telephone Laboratories.

Theoretical Physics and Some Experimental Nuclear Physics

H1. The Helium Wave Equation. JAMES H. BARTLETT, *University of Illinois.*—The wave equation for the normal state of helium has been written by Gronwall in the form $\nabla^2\psi+(1/z)(\partial\psi/\partial z)+(1/4r)(E-V)\psi=0$. If we let $\psi=e^F$, and $s=r^{\frac{1}{2}}$, it is possible to find a formal series for F in ascending powers of s, namely $F=F_1s+F_2s^2\cdots$. An analytical expression for F_1 has been found, and a possible F_2 has been calculated numerically. This procedure gets one away from the origin, and the integration can be continued outwards indefinitely, provided we are given E and two other adjustable parameters. The function ψ will have a node if E is greater than the lowest eigenvalue, and no node if E is below it. This enables us to enclose the lowest eigenvalue between two bounds, and to make their separation as small as we wish. Practical satisfaction of the boundary condition on ψ will be achieved by pushing the node outwards to larger and larger distances.

H2. A Field Formalism without Self-Action. T. A. WELTON, *University of Pennsylvania.*—It appears possible to interpret all physically real corrections to electrodynamic phenomena as arising from the action of the zero-point fluctuations of the electromagnetic field on the variables of the electron-positron field, or the reverse. If this is true, it seems somewhat pointless to use a formalism which contains other, unwanted effects, which must later be subtracted. A formalism has been developed in which a quantized electromagnetic field is allowed to act on the electron-positron field, but the motion of the quantized field is not affected by the charge-current vector. Instead, the interaction of particles is accounted for by a time-symmetric, unquantized interaction plus the quantized "free" field. The spontaneous emission probability is given in a trivial way. It seems likely that an improved treatment of the electron-positron field can be given along the same lines. For lack of such a treatment, however, the time-symmetric subtraction for the induced charge and current, previously described by this author,[1] has been used to accomplish the same result in a natural fashion. The mean-square fluctuation in position for a free electron is being calculated according to this formalism, and the result for the Lamb shift will be reported.

[1] T. A. Welton, Phys. Rev. **75**, 1321 (1949).

H3. Internal Coordinates of a Particle. H. C. CORBEN, *Carnegie Institute of Technology.*—If we ascribe to a particle four internal coordinates X^α and conjugate momenta P_α and suppose the particle to be a four-dimensional oscillator, its internal state $\psi(X^\alpha)$ is an eigenfunction of $(P_\alpha P^\alpha+s)\psi=m^2\psi$, where $s=X_\alpha X^\alpha$, the unit of length λ being related to the force constant of the oscillator. For $s>0$, well-behaved solutions for $l=0,\ \frac{1}{2},\ 1,\ \frac{3}{2},\ 2$ are $(\psi_{nl})_{\alpha\beta}\ldots=\Pi_{\alpha\beta}\ldots s^l e^{-s/2}L_{n+l}^{2l+1}(s)$, where $\Pi_{\alpha\beta}\ldots$ is the product of $2l$ unit orthogonal four vectors and $n+l$ is an integer $\geqslant 2l+1$. For given n, there are four independent solutions for $l=\frac{1}{2}$, six for $l=1$ etc., with parity $(-1)^{2l}$. If an internal spin operator is defined by $L_{\alpha\beta}=\frac{1}{2}(X_\alpha P_\beta-X_\beta P_\alpha)$ these correspond to particles of spin $l\hbar$. The exponential factor indicates that the particle is spread out in the neighborhood of the light cone through its center by an interval of order λ, requiring for its complete specification the ingoing and outgoing waves physically needed to observe it. The eigenvalues m are $274(n'+l)^{\frac{1}{2}}e^2\lambda^{-1}c^{-2}$, where n' assumes positive integral values. The stable elementary particles do not fit into this simple model and it is not possible from this to determine λ.

H4. The Spin Dependence of Nuclear Forces. ALEX E. S. GREEN, *University of Cincinnati.*—If two fermions are coupled five vectorially (scalar+four vector) with a five vector field then the chief explicit interaction will be $V_{ab}=(1-\beta_a\beta_b-\boldsymbol{\alpha}_a\cdot\boldsymbol{\alpha}_b)J$. This simple Diracian form has the following interesting properties: (a) The non-relativistic terms cancel; (b) Its Pauli equivalent to the order v^2/c^2 contains static, spin-spin, and tensor interactions as well as velocity dependent interactions; (c) The detailed physical conclusions deduced from it will be very sensitive to effects which are small compared to J. Numerous possible small effects will be discussed. Some of them lead to interactions which appear suitable for nucleons. Thus the strong spin dependence of nuclear forces may be due to relativistic forces which become important if the large non-

relativistic forces tend to cancel. Although conceptually simple this approach unfortunately brings to the fore the host of unsolved problems associated with relativistic effects. The greatest of these, namely the divergent interactions and infinite self energies, do not arise however, if J is our generalized meson potential (Phys. Rev. in press).

H5. Internal Pair Formation. M. E. ROSE, *Oak Ridge National Laboratory.*—The electron-positron angular correlation and total conversion coefficient has been calculated for internal pair formation and for arbitrary multipole order of the electric and magnetic radiation fields. The Born approximation is used and in the region of greatest experimental interest, $Z \lesssim 40$ and gamma-ray energy $\lesssim 2.5$ Mev, the consequent error should be negligible. Numerical results for multipole fields of order 2^l with $l = 1-5$ show that the ratio of total number of pairs formed with the angle between the particles equal to 0 (or a convenient small angle) and $\pi/2$ is sufficiently sensitive with l to determine multipole order. The total pair formation coefficient, in the region of interest, is of order 10^{-3} but is not quite so sensitive with l.

H6. Positon Theory. FREDERIK J. BELINFANTE, *Purdue University.*—From the conventional expressions of Dirac's electron theory for charge, energy and momentum densities and currents, in positon theory usually certain trivial infinite c-numbers are subtracted. For the proof of the Lorentz-invariance of the commutation relation in the quantum theory of wave fields, one often makes use of the fact that infinitesimal Lorentz-transformations can be represented by commutations with a certain operator. The commutation of a c-number with such operator, however, gives zero. Thus the infinite c-numbers subtracted in positon theory would behave like scalars, contrary to the tensor-behavior of the quantities in question. Thus these quantities cannot properly be considered as behaving like tensors both with *and* without subtraction. Fortunately, a direct check shows their correct tensor behavior *after* these subtractions. Statements about the transformation-behavior of the conventional *un*corrected expressions may then be considered as meaningless, since those quantities themselves by their divergence are meaningless. It might only be objected that also *after* the subtraction of these *trivial* infinities so many *other* infinities remain to be subtracted by some of the *ad hoc* methods proposed for such purposes, that even the proof of the tensor-character of the "corrected" expressions remains doubtful.

H7. Capture of μ^- Mesons by Deuterons. IRVING STEIN AND L. I. SCHIFF, *Stanford University.*—An investigation of the capture reaction of a μ^- (light) meson by a deuteron to yield two neutrons and a neutrino has been started, with the object of determining the dependence of the absolute rate of reaction and the emitted neutron spectrum on the meson coupling, the neutron-proton interaction and the neutron-neutron interaction. A preliminary result has been obtained, for the simplest case of scalar coupling when meson and neutrino are Dirac particles, under the assumption of zero range of nucleon interactions. Low but unequal neutron energies are favored in this case, and the life time for capture (ignoring decay) of a meson in its lowest Bohr orbit about a deuteron is about seven times that for a meson similarly bound to a proton.

H8. On the Vector Meson-Photon Interaction. GEORGE J. YEVICK, *Stevens Institute of Technology.*—Using the powerful methods developed by Feynman, we shall discuss the mass-term as the simplest illustration of these methods for the interaction between vector mesons and photons. The calculations are somewhat involved because of the complicated nature of the interaction Hamiltonian.[1] The relation of these considerations with the conventional second-order perturbation theory will be discussed.

[1] Kanesawa and Tomonaga, Prog. Theo. Phys. 3, 101 (1948).

H9. Nutation of the Nuclear Magnetic Moment.* ERWIN L. HAHN, *University of Illinois.*—Transient oscillations predicted by the quantum mechanical treatment[1] of a free spin in a large D.C. magnetic field H_0 and small perturbing r-f field H_1 have been experimentally confirmed in the liquid state using the method of nuclear induction.[2] An ensemble of spins, when suddenly subjected to an r-f field H_1 (which is left on) at angular frequency ω, behaves like a nutating classical macroscopic magnetic moment[3] if ω has the resonance value γH_0. In the coordinate system rotating at frequency ω a precession of the magnetic moment takes place about the r-f field H_1 (stationary in this system) at frequency $\omega_1 = \gamma H_1$, which is seen as a nutation in the laboratory system. Nutation frequencies have been measured from as low as 5 c.p.s. up to 1 kc for the H^1 and F^{19} nuclei in various liquid compounds. The time rate of decay of the nutations gives information about spin-spin coupling within molecules, revealing the nature of the chemical bond, independent of external field inhomogeneities. For H_1 intensities sufficiently large, nutation signals with periods shorter than the phase memory time T_2 are larger in amplitude than steady state resonance signals.

* Work done under auspices of ONR.
[1] I. I. Rabi, Phys. Rev. **51**, 652 (1937).
[2] Bloembergen, Purcell, and Pound, Phys. Rev. **73**, 679 (1948).
[3] N. Bloembergen, *Nuclear Magnetic Relaxation* (Monograph published by Martinus Nijhoff, The Hague, 1948).

H10. Nuclear Gyromagnetic Ratios. WILLIAM H. CHAMBERS AND DUDLEY WILLIAMS, *Ohio State University.*—Using the super-regenerative oscillator techniques described in earlier reports, we have observed radiofrequency resonance absorption peaks for Be^9, P^{31}, Cl^{35}, Rb^{85}, Cs^{133}, and La^{139} in a magnetic field in which the proton resonance is observed simultaneously. Preliminary results are given below:

Nucleus	Resonance Frequency / Resonance Frequency of Proton
$_4Be^9$	0.14034 ±0.00007
$_{15}P^{31}$	0.40498 ±0.00011
$_{17}Cl^{35}$	0.09799 ±0.00007
$_{37}Rb^{85}$	0.09661 ±0.00004
$_{55}Cs^{133}$	0.13093 ±0.00014
$_{57}La^{139}$	0.14116 ±0.00014

H11. Proton-Proton Scattering Experiment at 250 Mev. CHARLES L. OXLEY, *University of Rochester.*—Apparatus has been developed for use in the tank of the Rochester synchro-cyclotron to measure proton-proton scattering with the undeflected beam. A polyethylene target is used with coincidence counters detecting the scattered and recoil $p-p$ protons according to the scheme of Wilson and Creutz.[1] The counters are of scintillation type with light pipes to phototubes in the region of low fringing field. A measure of the incident beam of protons is obtained by observing the beta activity induced in the target by the reaction [2,3] $C^{12}(p, pn)C^{11}$. Preliminary experiments at full cyclotron energy (240 Mev) and at a laboratory scattering angle of forty-five degrees show that the $p-p$ scattering is detected efficiently against background. Cross sections relative to the carbon cross section will be presented. The apparatus is being redesigned to cover a range of scattering angles. Provision will also be made to move the target and counters to smaller cyclotron radii, thus covering the energy range down to about 100 Mev. This work is supported by the joint program of the ONR and AEC.

[1] R. R. Wilson and E. C. Creutz, Phys. Rev. **71**, 339 (1947).
[2] W. W. Chupp and E. M. McMillan, Phys. Rev. **72**, 873 (1947).
[3] E. M. McMillan and R. D. Miller, Phys. Rev. **73**, 80 (1948).

H12. Self-Absorption and Backscattering of Soft Beta-Radiations.* L. E. GLENDENIN, *Massachusetts Institute of Technology*, AND A. K. SOLOMON, *Harvard Medical School.*—Self-absorption and backscattering effects of the soft β-radiations of S^{35} (0.17 Mev) and Ca^{45} (0.26 Mev) have been investigated, using isotopes obtained from Oak Ridge. By comparison of weightless sources evaporated on thin collodion films ($\sim$20 μg/cm^2) with identical sources on "infinitely thick" backings of various metals (Be, Al, Fe, Cd, Pb), the variation of backscattering with atomic number was determined. As first noted by Yaffe, a marked increase (factor of $\sim$1.5) in backscattering was observed when the source was evaporated directly on the metal surface as compared with an equal source first evaporated on a thin collodion film and then placed against the metal, e.g., for S^{35} on Pb a backscattering effect of 90 percent was obtained in the former case as compared with 60 percent in the latter. Self-scattering (internal backscattering) as a function of the average atomic number of the sample was also determined for S^{35} by intercomparison of the counting rates of thick samples of benzidine sulfate (average $Z=4.5$), $BaSO_4$ (average $Z=17.3$), and $PbSO_4$ (average $Z=21.7$). The self-scattering effect is in approximate agreement with the backscattering curve for sources evaporated directly on metals. The self-absorption coefficient for Ca^{45} in $CaCO_3$ mounted on glass, Al, Fe, and Cu is 0.09 ± 0.01 cm^2/mg. The coefficient for S^{35} in benzidine sulfate mounted on Be ($Z=4$) is uniformly 0.18 ± 0.01, whereas on Al ($Z=13$) the coefficient is initially 0.22 ± 0.01 (due to enhanced reflection by the Al), dropping to 0.18 for sample thicknesses >6 mg/cm^2.

* This work has been supported in part by ONR and AEC.

H13. The Lifetime of Positrons in Matter. JAMES W. SHEARER AND MARTIN DEUTSCH, *Massachusetts Institute of Technology.*—Delayed emission of annihilation radiation has been observed when positrons from Na^{22} are stopped in various gases. The time of creation of each positron was marked by the 1.3 Mev nuclear gamma-ray from Na^{22}. Delay times between 1.8×10^{-7} and 6×10^{-7} sec. were used. Preliminary results for the mean life τ are listed below together with the apparent electron cross section σ in terms of $\sigma_0=\pi r_0^2 c$. The fact that σ has about twice the Born approximation value σ_0 is probably due to the attraction between positron and electron. The tendency for σ to decrease with increasing pressure may be connected with the slowing down mechanism at very low energies or perhaps to the formation of positronium:

Gas	$\tau\times10^7$	σ/σ_0
N_2 0.5 atm.	2.6 ± 0.3	2.8
1 atm.	1.5 ± 0.15	2.4
2 atm.	1.0 ± 0.15	1.8
A 0.5 atm.	2.9 ± 0.6	1.9
1 atm.	1.6 ± 0.3	1.8
2 atm.	1.3 ± 0.2	1.1
CH_4 1.5 atm.	1.3 ± 0.15	2.7

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

H14. Multiply Scattered γ-Rays: Angular Distribution.* L. V. SPENCER AND FANNIE JENKINS, *National Bureau of Standards.* (Introduced by U. Fano.)—In an investigation of the angular distribution of multiple scattered gamma-rays, the case of an infinite medium filled uniformly with a mono-directional source is considered. The solution is given by an expansion in zonal harmonics the coefficients of which are determined by solving integral equations of the following form: $\mu(\lambda)N_l(\lambda)=\int^{\lambda}_{\lambda_0} d\phi_{\lambda'\lambda} N_l(\lambda')P_l(1-\lambda+\lambda')d\lambda' + P_l(1-\lambda+\lambda_0)d\phi_{\lambda_0\lambda}$, where λ is the wave-length in compton units, $d\phi_{\lambda'\lambda}$ is the differential compton scattering cross section, $N_l(\lambda)$ is the coefficient of the l'th harmonic, and $\mu(\lambda)$ is the total absorption coefficient. Numerical computations have been made for aluminum, $\lambda_0=0.1$. These show that the solution for $\lambda>2$ has a maximum approximately at $\theta=\cos^{-1}\times(-3+\lambda-\lambda_0)$ which behaves like a wave traveling back and forth between the poles as λ increases, superposed on a continually increasing isotropic distribution. A simple qualitative explanation can be given for this result. Computations for heavier materials are in progress.

* Work supported by an ONR grant.

Nuclear Physics, Mostly Neutron Physics

J1. A Search for Some Rare Stable Isotopes.* HENRY E. DUCKWORTH, ROBERT F. BLACK, AND RICHARD F. WOODCOCK, *Wesleyan University.*—The Wesleyan University double-focusing mass spectrograph has been used to search for rare stable isotopes of a number of the heavier elements. A brief description will be given of the mass spectrograph and of the experimental procedure employed in this search. Mass spectra will be shown for zirconium, palladium, tellurium, gadolinium, tungsten, and lead.

* This work has been done under contract with the AEC.

J2. Nuclear Energy Levels in N^{15} and N^{16}. L. D. WYLY, *Yale University.**—The reported mass values for N^{16} have shown large discrepancies as determined from the β-decay of N^{16} and from the $F^{19}(n\alpha)N^{16}$ reaction. Ammonia, enriched to 61.5 percent in N^{15}, has been bombarded with deuterons to obtain the Q values of the $N^{15}(dp)N^{16}$ reaction. A ground state Q value of 0.21 ± 0.15 Mev was obtained, thereby giving a N^{16} mass of 16.01121 ± 0.00023 MU. The Q values for the associated $N^{14}(dp)N^{15}$ reaction were also determined and are listed in Table I, together with the relative intensity as obtained at 90° for a deuteron energy of 3.32 Mev.

TABLE I.

Mev	Relative intensity
8.61 ± 0.1	1
3.29 ± 0.1	5
2.30 ± 0.1	2
1.38 ± 0.1	25.0

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

J3. The Reactions $N^{14}(n,p)C^{14}$ and $He^3(n,p)H^3$ and the Neutron-Hydrogen Mass Difference. W. FRANZEN,[1] J. HALPERN, AND W. E. STEPHENS, *University of Pennsylvania.*[2]—The pulse height distributions arising from the reactions $N^{14}(n,p)$ and $He^3(n,p)$ induced by slow neutrons have been studied in a cylindrical ionization chamber containing a purified mixture of 2 atmos. A$+\frac{1}{10}$ atmos. $N_2+\frac{1}{2}$ atmos. He ($He^3/He^4=4.9\times10^{-5}$). The distributions due to $N^{14}(n,p)$ and $He^3(n,p)$ are well resolved, the ratio of total ionizations being 1.217. In a separate experiment, the ratio of the total ionizations due to $N^{14}(n,p)$ to that of Po-α-particles was found to increase by 3 percent as the concentration of N_2 in nitrogen-argon mixtures was increased from 10 percent to 100 percent. If proportionality between energy and total ionization in pure argon is assumed, the energy equivalent of the ionization produced by $N^{14}(n,p)$ compared to that produced by Po-α-particles is 628 ± 4 kev, whereas a similar comparison for $He^3(n,p)$ yields 764 ± 10 kev. The ratio of these values agrees with the ratio of the total ionizations due to the two reactions obtained when observed simultaneously, and their difference agrees with the β-end points of C^{14} and H^3. If possible systematic errors due to the assumption of a constant energy per ion in argon are disregarded and the ionization is assumed to give the Q values for the reactions, these results give $n-H=783\pm4$ kev, in good agreement with several recent measurements.

[1] Mary Amanda Wood Research Associate.
[2] Supported partly by the joint program of the ONR and AEC and aided by a grant from the Committee on Advancement of Research of the University of Pennsylvania.

J4. Neutron Distributions in Cylindrical Geometry. HENRY FAUL AND CLARK GOODMAN, *Massachusetts Institute of Technology.**—Thermal and cadmium difference neutron distributions from a 1-g Ra-Be source have been measured with indium detectors in pipes (4 to 8 in. in diameter) surrounded by water and by brines of various concentrations (effectively infinite media). The results are of interest in the design of orifices in nuclear shields and in the logging of oil wells. The axial neutron distribution in the empty pipes is closely approximated by a simple exponential at distances greater than 15 cm from the source. Slowing-down and absorption in an average barite drilling mud and in water are almost identical. A 2-in. layer of water (or mud) between the logging probe and the geological formation effectively obscures the influence of the formation, and two $\frac{1}{4}$-in. layers of iron separated by $\frac{1}{4}$ in. of water produce a similar effect. Two coaxial iron pipes (4-in. and 5-in.) surrounded by saturated brine reduce the thermal distribution to within a few percent of the resonance flux. The net hydrogen content of the formation can be estimated roughly from the resonance data. A single probe can be designed to measure the intensity and slope of both thermal and epithermal neutron distributions. The high thermal capture cross section of chlorine permits identification of brine in a reservoir rock behind casing under favorable conditions.

* This is a joint undertaking of the Massachusetts Institute of Technology and the ONR.

J5. Determination of the Phase of Scattering of Neutrons and of Incoherent Residual Scattering Cross Sections. P. J. BENDT AND I. W. RUDERMAN, *Columbia University.*—The phase in which neutrons are scattered by various elements, and the coherent scattering cross sections of these elements, have up to now been obtained principally by measurements of the intensities of Bragg reflections from suitable crystals. For such measurements a crystal spectrometer and an intense neutron source such as a pile are needed. We wish to point out that similar information can be obtained more readily and directly from transmission experiments. In a typical experiment, the Columbia neutron velocity spectrometer was used to obtain transmission curves for two pure elements and for a substitutional solid solution of the two, for neutron wave-lengths up to and beyond the cut-off wave-length for Bragg reflections, λ_c. The cross section *vs.* neutron wave-length curves in the region beyond λ_c, when extrapolated to zero wave-length, give directly the residual incoherent scattering cross sections, σ_r. The temperature-dependent part of σ_r may be determined by repeating the transmission experiments at liquid nitrogen temperature. The value of σ_r for the solid solution shows whether the two constituent elements scatter neutrons in the same or in opposite phases, and gives information about order-disorder in the alloy. The Cu-Ni, Mn-Ni, and Mn-Fe systems are now being studied.

J6. Reflection of Neutrons from Magnetized Mirrors. D. J. HUGHES AND M. T. BURGY, *Argonne National Laboratory.*—In a recent investigation of small angle scattering of neutrons in iron[1] the observed deviations were explained as the magnetic refraction of neutrons at domain boundaries. According to this explanation there should be two indices of refraction for neutrons in iron, and the possibility exists of demonstrating this double refraction in a more striking way and of using it for the production of polarized neutrons. The present work was designed to measure the indices of refraction in iron by obtaining two critical angles for reflection from an iron mirror and to investigate the possibility of producing highly polarized beams of neutrons by reflection. BeO-filtered neutrons (4.4A) were used to increase the expected critical angles to 14.2 and 30.7 minutes for the two spin states. The two critical angles have been observed and are in good quantitative agreement with theory. The reflection as a function of magnetization direction shows that the classical electron-neutron interaction originally used by Bloch[2] is incorrect. Reflection of the polarized neutrons produced by one magnetized mirror have been reflected from a second mirror to measure the polarization.

[1] Hughes, Burgy, Heller, and Wallace, Phys. Rev. **75**, 565 (1949).
[2] F. Bloch, Phys. Rev. **50**, 259 (1936); **51**, 994 (1937).

J7. Neutron Spectra from (p, n) Reactions with 16-Mev Protons.* P. C. GUGELOT AND M. G. WHITE, *Princeton University.*—By means of track length measurements of proton recoils in photographic emulsions neutron spectra are obtained from different elements bombarded by 16-Mev protons. About 1-Mev thick targets of Be, Al, Fe, and Au have been investigated. For each reaction *ca.* 2000 tracks are measured and special exposures made to obtain information about the background of scattered neutrons which might distort the spectra and to be able to estimate the reliability of the method. The neutron spectra can be represented by $dN/dE = \text{const.} \times Ee^{-E/kT}$ for neutron energies $E > 2$ Mev. The values for kT decrease from 2.4 Mev for Be, 1.1 Mev for Al, 0.94 Mev for Fe to 0.77 Mev for Au. The Be neutron spectrum consists of two parts; for neutron energies > 4.5 Mev, $kT = 2.4$ Mev and for neutrons slower than 4.5 Mev, $kT = 0.9$ Mev. A preliminary exposure with a Be target bombarded by 8-Mev protons indicates that kT may decrease with decreasing energy of the incoming proton. This behavior may show that properties other than the level-density of the residual nucleus are necessary to explain the general form of these spectra.

* Supported in part by the Joint Program of the ONR and the AEC.

J8. Evidence for Broad Nuclear Energy Levels in Lead.* R. K. ADAIR, H. H. BARSCHALL, C. K. BOCKELMAN, R. L. HENKEL, AND R. E. PETERSON, *University of Wisconsin.*—The total neutron cross section of lead was measured over an energy range of from 30 to 750 kev, using an energy spread of 10 kev. Certain interesting energy intervals were investigated with an energy resolution of about 5 kev. The cross section was determined by means of simple transmission measurements as previously described.[1] The lead cross section diminishes from 12 *b* at 30 kev to 6 *b* at 750 kev. Three distinct peaks were resolved, which appear to have a natural width of the order of 5 kev. They are attributed to elastic scattering resonances, most likely resulting from energy levels in Pb^{209}, the compound nucleus formed from the closed shell nucleus Pb^{208}. Two of the peaks, at 350 and 525 kev, are preceded by dips, explained as the result of destructive interference between resonance and potential scattering. No evidence was found for such a dip before the 725-kev peak. No peaks were found in bismuth, which was surveyed from 30 to 600 kev with a neutron energy spread of 10 kev.

* This work was supported in part by the AEC.
[1] Adair, Barschall, Bockelman, and Sala, Phys. Rev. **75**, 1124 (1949).

J9. Fast Neutrons from Bombardment with the Cyclotron Particles.* A. J. ALLEN AND J. F. NECHAJ, *University of Pittsburgh,* AND K. H. SUN AND B. JENNINGS, *Westinghouse Research Laboratories.*—The total fast neutron yield, N, from thick Be, Al, Cd, Au, and Bi targets bombarded by 15-Mev deuterons, measured with a $S^{32}(n, p)P^{32}$ detector,[1] was found to be $(19, 6.4, 1.2, 0.22, \text{and } 0.14) \times 10^9$/sec./$\mu$A, respectively. As a rule of thumb, N may be estimated within a factor of two from the nuclear charge, Z, of the target by the relation: $\log N = 10.25 - 0.022Z$. The angular distribution (0° to ±160°) shows a pronounced forward peak with angular widths at half-intensity of 42°, 42°, 98°, 102°, and 119° respectively (in the laboratory system). The total yields for < 7.5-Mev protons and 30-Mev alphas on thick Be are $(0.086 \text{ and } 14) \times 10^9$/sec./$\mu$A and the angular widths 70° and 80°, respectively. The presence of a strong peak in the forward direction only is common in all cases studied, irrespective of the type of bombarding particles

and target. These measurements are being extended to targets of other monoisotopic nuclei as well as commonly used elements.

* Assisted by ONR, AEC, and Research Corporation.
[1] Allen, Nechaj, Sun, and Jennings, Bull. Am. Phys. Soc. **24**, No. 4, 36 (1949).

J10. Neutron Spectrum from $N^{15}(d, n)$.* EMMETT L. HUDSPETH AND CHARLES P. SWANN, *Bartol Research Foundation.*—Gas targets of normal and of N^{15}-enriched N_2O have been bombarded with 1.2-Mev deuterons, and the neutron spectra have been observed on photographic plates placed at 0° to the bombarding beam. Two groups previously reported[1] from $N^{14}(d, n)$ were observed, with evidence for the production at our bombarding voltage of a third group of lower energy. Neutron groups from $N^{15}(d, n)$ were observed at 11 Mev and at approximately 4.5 Mev. The latter group was broader and several times as intense as the group at 11 Mev. There is evidence for a third group at 2.5 Mev, but it may belong entirely to the N^{14} reaction. Excited states of O^{16} in the vicinity of 6.5 Mev are well known from studies by other experimenters of the reaction $F^{19}(p, \alpha)$ and from the β-decay[2] of N^{16}. Our results reveal these levels (unresolved), and no lower excited state is observed.

* Assisted by the Joint Program of ONR and AEC.
[1] Stephens, Djanab, and Bonner, Phys. Rev. **52**, 1079 (1937).
[2] H. S. Sommers, Jr., and R. Sherr, Phys. Rev. **69**, 21 (1946).

J11. Isotopic Spectra of Lead. THURSTON E. MANNING, *Yale University.*—Using a sample[1] of lead sulfate from lead enriched to 27 percent in the isotope 204, the isotopic shifts of several blue and ultraviolet lines in the spectrum of neutral lead have been examined. The source used in these investigations, a hollow cathode tube especially designed to use and conserve small amounts of valuable material, will be described. The shifts are of the order of 0.08 wave numbers between successive even isotopes. Analysis with a crystalline quartz Lummer plate of 200-mm length and 7.34-mm thickness shows that the 204–206 shift is in some cases smaller than the 206–208 shift by perhaps 10 percent of the smaller (e.g., for λ4058 the shifts are 0.07 and 0.08 wave numbers). Such results confirm conclusions previously drawn from shifts of the odd-numbered isotopes that the isotopic shifts in heavy elements cannot be explained in any case by the mass difference alone, as has sometimes been suggested; the results will be discussed from the viewpoint of the nuclear volume effect utilized by Rosenthal and Breit.

[1] Supplied by the Carbide and Carbon Chemicals Corporation and allocated by the Isotopes Division, U. S. AEC.

Papers Not Classed Elsewhere

K2. Extinction Coefficients for Oxygen in the Schumann Region. R. J. LANG AND A. R. J. STEPHENSON, *University of Alberta.*—Absorption measurements have been made in oxygen up to pressures of one atmosphere in the region between 2050 and 1600A by means of a 3-meter vacuum spectrograph. The gas was contained in a Pyrex glass cell with fluorite ends which was placed just behind the slit. The source used was a spark in an atmosphere of nitrogen, and a spectrum very rich in lines was obtained from tungsten steel electrodes. Most of the known bands of oxygen in the region were found and a few new members. By using the oxygen at different pressures it is found that Beer's law does not hold.

K3. On Exchange Energy in He_3 Assemblies. LOUIS GOLDSTEIN AND MAX GOLDSTEIN, *Los Alamos Scientific Laboratory.*—An account will be given of a series of studies on the role of the identity exchange energy in He_3 assemblies at liquid He_3 densities. Using, at the highest density, assumedly near the one realized at absolute zero, the free atom individual wave functions together with the well-known He-He mutual potential energy, one finds that the exchange energy alone favors the parallel alignment of all the nuclear spins (the latter being $\hbar/2$). However, the smaller free particle kinetic energy associated with the state of balanced spins as compared with the same quantity in the all-spin parallel state compensates, in this crude model, for the favorable all-spin parallel exchange energy excess over the balanced spin state exchange energy. Hence, in this free particle approximation liquid He_3 has no nuclear ferromagnetism. Clearly, no definite conclusion can be drawn from the free particle model as to the actual magnetic properties of liquid He_3. Other He models are being studied.

K4. Rotational Dispersion of Ultrasonics in Deuterium and Hydrogen.* JAMES L. STEWART AND ELLEN S. STEWART, *Rutgers University.*—Dispersion in the velocity and the associated absorption peak for ultrasonics, caused by the failure of the rotational degrees of freedom to follow the temperature cycle, were observed first in hydrogen and have now been discovered in deuterium. Measurements at 303°K in commercial deuterium (≃0.5 percent impurity) show that the dispersion starts at four megacycles per atmosphere and continues to about 100 Mc/atmos., the velocity increasing 9 percent above the classical value. These determinations were made using a variable-path ultrasonic interferometer with a crystal of frequency 1.95 Mc. The pressure was varied from one atmosphere to 0.02 atmos. The dispersion region centers about 20 Mc/atmos. compared with less than 10 Mc/atmos. for purer hydrogen. The authors have also found a marked dependence of the dispersion frequency on very small amounts of impurity in the case of hydrogen. This probably applies to deuterium also, making any comparison between the two premature until the large amount of impurity in deuterium has been removed. Since the hydrogen impurity in deuterium, which amounts to 0.2 percent, cannot be readily removed, it may limit the significance of any comparison. Quantitative data on the deuterium and hydrogen velocity and absorption curves will be presented and their theoretical interpretation discussed.

* This work was supported by the Rutgers University Research Council.

K5. Bioelectric Potential Transients Accompanying Closing Movements of the Lobes of Venus' Fly-Trap. OTTO STUHLMAN, JR., *University of North Carolina.*—The method used for measuring the bioelectric potentials is a modified Wheatstone bridge arrangement designed by Burr, Lane, and Nims for measuring slow changes in mammalian potentials. Contact potentials of the electrodes across which the bioelectrical potentials are measured was minimized by using a pair of Ag-AgCl reversible electrodes in dilute KCl, terminating in a glass capillary containing a small asbestos-fiber wick, which served as the contact electrode on the surface of the plant where the e.m.f. originated. Closure of the trap-like structure at the end of the spatulated petiole of Venus' Fly-Trap normally follows when any one of the spike-like trigger hairs or the irritable inner epidermis is stimulated. The speed of closure depends on the pattern of excitation, which was hypothesized to originate as a localized destruction of the degree of polarization, which progressively spreads as an equipotential electrical wave front, propagated over the surface of the lobe at about 3.0 cm per sec. The excitatory wave front was found to be a negative potential of about 0.05 volt for summer growth or as low as 0.01 volt for winter growth plants. It is measurable as a diphasic or monophasic potential pulse depending on the position of the nonpolarizable electrodes. The exact shape, speed, and origin of the electrical impulse is being explored with the aid of an oscillograph.

K6. Solar Position Calculator. DONALD W. DUNIPACE, *Libby-Owens-Ford Glass Company.*—The important effect of

the sun on our lives is well known. A primary factor in its influence is its position with respect to a given location on the earth. Two calculators have been developed which give geometric relations between the sun and various geographic locations for any time of the day and year. One calculator can be set up to give such quantities as altitude, air mass, direction, and angle of incidence on walls facing north, east, south, or west. This calculator consists of a transparent overlay on an opaque underlay, and the patterns can be constructed by using elliptical, circular, and straight lines. The other calculator gives angles pertinent to architectural designs. For accuracy, convenience, and speed of operation, these calculators are comparable to a slide rule.

K7. Pentode Counting or Control Ring.* BENJAMIN L. MOORE, *Harvard University.*—The 6AS6 pentode has a suppressor grid voltage plate current characteristic similar to that of the control grid, and has been used in a counting or control ring whose input is essentially independent of amplitude and wave shape. The basic element of this ring is two pentodes connected as a direct coupled type trigger pair using the screen grids as the plates. A number of these trigger pairs are arranged in a ring with the two tubes of each trigger pair opposite each other. The plate of each tube is connected to the screen of the next tube in the ring. If initially the first n tubes are conducting, then the next n tubes must be non-conducting. By applying positive pulses alternately to the suppressor grids of all odd tubes and then to all even tubes, the ring will step once for each pulse. Control voltages corresponding to one or more states of the ring may be obtained very easily.

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

K8. A Static Storage System Utilizing Magnetic Retentivity.* W. D. WOO AND AN WANG, *Harvard University.* (Introduced by B. L. Moore.)—Magnetic cores with a rectangular hysteresis loop[1] have been used in a storage system which requires no mechanical motion. The binary digit "1" is stored as a positive residual flux, and the binary digit "0" as a residual flux in the opposite direction. When a negative probing field is applied to the core, a large voltage is induced in another winding if the digit stored has been a "1," and very small voltage if it has been a "0." The induced voltage in the former case is large enough to magnetize another core of identical construction. Binary digits can thus be transferred from one core into another. If two such cores are arranged in a pair, one binary digit can be transferred back and forth between them. If many cores are arranged in series, binary digits can be advanced along the line. The present upper limit of the speed of propagation is about 30,000 to 40,000 digits per second, and there is no lower limit.

* This work has been supported by the United States Air Force.
[1] The cores are furnished through the courtesy of Allegheny Ludlum Steel Corporation.

K10. Ion Exchange and Chromatography. H. L. FINSTON AND R. M. DYER, *Ohio State University.*—The ion exchange techniques developed in the Manhattan project, and described in detail by Ketelle and Boyd[1] have been tried and found to yield excellent results with mixtures of rare earth activities of moderately long half-lives. The time involved in this procedure, however, made certain modifications necessary in order to work with activities of shorter half-life. It was found that a short column of "Dowex 50" could be extruded after first being frozen. A sample of Tm was bombarded for 6 hours with deuterons in the cyclotron, dissolved and adsorbed at the top of a column 21 cm long with a cross section of 0.28 sq. cm. The column was operated for 5 hours, and then extruded. The column was cut into short lengths and the distribution of activity determined. Four definitely different fractions were obtained. In another investigation the chromatographic method of separation described by Schwab and Jockers[2] has been applied to a separation of Cr, V, and Mn produced by a deuteron bombardment of Cr. Three fractions were obtained with characteristics corresponding to those of Cr, V, and Mn, respectively.

[1] Ketelle and Boyd, J. Am. Chem. Soc. **69**, 2800 (1947).
[2] Schwab and Jockers, Angew. Chem. **50**, 546 (1937).

K11. Use of the Density-Gradient Tube in the Study of Finely Divided Materials. WILLIAM H. OTTO, *Owens-Corning Fiberglas Corporation.*—A vertical linear density gradient is established in a glass tube by the diffusion of liquids or solutions of different density and can be maintained in a stable condition for prolonged periods. The device is particularly useful in the density determination of finely divided materials or samples of extremely low mass such as fine glass fibers and provides a means for the study of the density distribution of a mixed-density sample. The application of the density-gradient tube to the study of glass fibers is discussed with particular regard to density differences between the bulk glass and the glass fiber form.

K12. Presentation of Mass Spectra with a Cathode-Ray Oscillograph. J. W. TOWNSEND, JR., *Williams College.*—A new approach to electronic presentation of mass spectra with a cathode-ray oscillograph has been undertaken. Previously this has been achieved by sweeping the accelerating potential of the mass spectrometer with a sawtooth voltage, and detecting the resultant ion currents by means of d.c. or pulse amplifiers. In the new system, the rate of production of ions in a conventional Nier type 60° spectrometer is modulated by a 1000 c.p.s. voltage, and the ion current at the collector detected by a specially designed a.c. amplifier. This amplifier is composed of two parts, a low noise preamplifier employing a miniature "acorn" type pentode mounted as close to the collector as possible, and a main amplifier whose band pass is restricted to 100 c.p.s. by a feed-back network. The 10-c.p.s. sawtooth voltage, of sufficient amplitude to cover the desired range of masses, is synchronized with the horizontal sweep of the oscillograph, while the amplifier output is applied to the vertical plates. Results have been encouraging. It is possible to detect peaks as small as 4×10^{-14} ampere, with good linearity and resolution. The system has been especially valuable in adjusting and focusing the newly completed spectrometer.

Magnetic Resonance; Non-Metallic Solids

L1. The Optical Detection of Radiofrequency Resonance.* F. BITTER, *Massachusetts Institute of Technology.*—Calculations are made of the frequency, intensity, and polarization of the light emitted by an atom in a doublet P to a doublet S transition in a weak magnetic field having an oscillating component. Near resonance, or when the frequency of the oscillating component approaches the Larmor frequency of one of the two states involved in the radiation process, all of the quantities calculated are modified. Qualitatively similar results are to be expected for other transitions. Observations in very weak fields would be of particular interest because they would give information on nuclear as well as atomic g-factors. Under such conditions, the Zeeman components will, in general, not be resolvable, and the only observable effect will be a change in the polarization of the edges of a spectral line at resonance. It is further shown that very small changes in this polarization structure are theoretically detectable.

* This research has been supported in part by the Signal Corps, the Air Materiel Command, and ONR.

L2. Some Measurements of Nuclear Spin-Lattice Relaxation Times in Solids. E. H. TURNER, A. M. SACHS, AND E. M. PURCELL, *Harvard University.*—Nuclear spin-lattice relaxa-

tion[1] was studied as a function of field strength and temperature to obtain information about the relaxation mechanism in crystals. Relaxation times, T_1, greater than 5 seconds were found by observing at low power the growth of the center of a previously "saturated" absorption line. For T_1 less than 30 seconds, a saturation curve method[1] was used. For substances with a long T_1, the rate of approach to equilibrium at low fields was studied by adiabatic changes between the low field and a field suitable for measurements. Substances which were investigated include ice, benzene, and sucrose. One sample of ice had the longest T_1 observed to date: 210 min. at 88°K. Benzene exhibited a minimum in its T_1 *versus* temperature curve qualitatively similar to the minima described in the next paper. The T_1 of a single sucrose crystal was proportional to field strength and decreased fast with increasing temperature. Interpretation of the results will be discussed.

[1] Bloembergen, Purcell, and Pound, Phys. Rev. **73**, 679 (1948).

L3. A Study of Internal Motion in Ammonium Salts by Nuclear Spin-Lattice Relaxation Time Measurements. A. M. SACHS, E. H. TURNER, AND E. M. PURCELL, *Harvard University.*—Gutowsky and Pake* have reported sharp line-width transitions in ammonium salts at temperatures 100° or more below the specific heat anomalies. Using methods outlined in the preceding paper, we have measured nuclear spin-lattice relaxation times (T_1) of some ammonium salts from 85°K to 270°K at 14.2 and 30 mc/sec. Sharply defined minima of T^1 are found at temperatures from 45° to 75° above the line-width transitions, with the minima of the 30-mc/sec. curves occurring approximately 9° above those of the 14.2-mc/sec. curves. Assuming relative motion of protons as the relaxation mechanism, the characteristic time of this motion, τ_c, has been deduced from the general formula of Bloembergen, Purcell, and Pound** and the experimental data. The result is described by $\tau_c = A \exp(a/T)$. All of the data, including the temperature of the line-width transition, are consistent with a single choice of the constants A and a for each salt. For example, in NH_4Br, $a = 1700$ deg., $A = 1.2 \times 10^{-13}$ sec. A discussion will be given in terms of barrier penetration by NH_4 tetrahedra.

* H. S. Gutowsky and G. E. Pake, J. Chem. Phys. **16**, 1164 (1948).
** Bloembergen, Purcell, and Pound, Phys. Rev. **73**, 699 (1948).

L4. Measurements of Spin-Lattice Relaxation Times in Paramagnetic Solids by the Saturation Method. C. P. SLICHTER* AND E. M. PURCELL, *Harvard University.*—The measurement of spin-lattice relaxation times, T_1, in paramagnetic solids has been performed extensively at low temperatures by the study of absorption or dispersion at frequencies of the order of $1/2\pi T_1$.[1] We have extended the measurement of T_1 at room and dry ice temperatures by studying saturation in the absorption of microwave energy at the Larmor frequency in analogy to the experiments of Bloembergen, Purcell, and Pound.[2] The sample was held in a resonant cavity terminating one arm of a magic tee bridge. Since a pulsed magnetron was used to generate the high microwave magnetic fields (~30 gauss) needed to saturate the samples, slight modifications were made in conventional bridge techniques because of transient effects associated with the short pulses and high Q cavity. Relaxation times ($\sim 10^{-8}$ sec.) have been determined for manganese ammonium sulfate, manganese sulfate, and copper sulfate both at room temperature and at −78°C, and at room temperature for a free radical kindly supplied by the Bell Laboratories.

* Socony Vacuum Predoctoral Fellow in Chemical Physics.
[1] C. J. Gorter, *Paramagnetic Relaxation* (Elsevier Publishing Company, New York, 1948).
[2] Bloembergen, Purcell, and Pound, Phys. Rev. **73**, 679 (1948).

L5. Hyperfine Structure of the Paramagnetic Resonance Spectrum of Cobalt. B. BLEANEY AND D. J. E. INGRAM, *Clarendon Laboratory, Oxford.* (Introduced by E. M. Purcell.)—Following the discovery of Penrose[1] that the paramagnetic resonance spectrum of diluted copper potassium sulphate shows a hyperfine structure, measurements have been made on a mixed crystal of cobalt and zinc ammonium sulphate containing Co:Zn in the ratio 1:1000. The Co^{++} ion is found to have exact tetragonal symmetry within the experimental error, with a single electronic transition whose g-value varies from 3.0, perpendicular, to 6.2 parallel to the tetragonal axis. The absorption line is split up into eight unequally spaced components due to the nuclear spin (7/2) of Co^{59}. The over-all separation of the *h.f.s.* varies from 0.14 kg to 0.67 kg, having the same anisotropy as the crystalline electric field. The half-width at half-intensity of the lines is about 7 gauss, most of which is attributed to the protons of the water of crystallization. At 90°K the line width is about 1400 gauss, corresponding to a spin-lattice relaxation time of 7×10^{-12} sec. ($=\rho/2\pi$ in Gorter's[2] nomenclature).

[1] Penrose, unpublished owing to illness of author.
[2] J. Gorter, *Paramagnetic Relaxation*, Elsevier Publishing Company, New York, 1948).

L6. The Solids Condensed from Carbon Monoxide by Alpha-Particles. JOHN H. L. WATSON, *Edsel B. Ford Institute for Medical Research;* MARCEL VANPEE, *University of Minnesota;* AND S. C. LIND, *Carbide and Carbon Chemicals Corporation.*—An electron microscopic and x-ray diffraction study was made of the residues formed by bombardment by alpha-rays from radon of carbon monoxide gas. Carbon monoxide, when polymerized by alpha-rays from radon exhibits a particulate structure. The particles have recognizable shape and have nearly the same dimensions in all directions. There are two components in the residue. The first are solid particles which are rigid aggregates of graphitic flakes. The second is a viscous liquid material which surrounds the particles, may exist within them, and often joins them one to the other by short necks. The mean diameter of the material taken from the base of the flask is about 0.5 and from the neck of the flask about 0.41 micron. About 15 percent of the silhouette images of the particles appear hexagonal in shape. The percentage of particles having this shape is undoubtedly even higher than this, since non-hexagonal images often are accompanied by hexagonal shadows. The approximate uniformity of particle dimensions in all directions and the increase in particle size toward the base of the flask indicate that they are formed and grow in the gas phase, and that the larger ones fall out under gravity.

L7. Thermal Conductivity and Heat Capacity of Beryllium Carbide. CHARLES E. TEETER, JR., *Fairchild Engine & Airplane Corporation.*—Beryllium carbide is an interesting substance which has recently become available in laboratory quantities. Among its physical properties which are being studied at NEPA are thermal conductivity and heat capacity. The thermal conductivity of a hollow cylinder of beryllium carbide was measured in a preliminary fashion by a radial heat flow method. A central globar heater was used to raise the inside of the cylinder to temperatures up to 950°C (1740°F). This inside temperature, as well as the temperature of the outside, was measured by thermocouples and the thermal conductivity calculated by the conventional formula. Further experiments are continuing to improve the accuracy. The heat capacity of beryllium carbide in powdered form was measured by a modification of the so-called "drop method." Capsules of refractory metals (copper was first used, than stainless steel, and finally nickel) were heated in a furnace and dropped into a copper block in a water calorimeter. To correct for heat losses during the drop, empty capsules were heated to various temperatures, and dropped in a similar manner. Results were obtained for the enthalpy and mean heat capacity from room

temperature to 200–1100°C (392–2012°F). From the smoothed curve for the enthalpy, the heat capacity, C_p, was calculated.

L8. A Model for the Plastic Flow of Oriented Nylon Fibers. JOHN KAUFFMAN AND WALLER GEORGE, *Naval Research Laboratory.*—Studies of the changes in broadening shown by x-ray fiber patterns have been associated with the stress-strain relation for highly oriented Nylon fibers (Type 200). The angular broadening of the equatorial spots reduces with increasing strain up to the inflection point of the stress-strain curve. For larger strains this broadening increases at a decreasing rate. The radial broadening of these spots remains essentially constant up to the strain at the inflection, then increases at a decreasing rate to rupture. Assuming a crystallite model, these data indicate that the initial straining is accompanied by the rotation of crystallites toward positions parallel to the fiber axis. This process appears to terminate in the inflection region of the stress-strain curve and is replaced by a process of crystallite breakup. The broadening in the later phase of straining is analogous to that found recently by Patterson and Orowan[1] for aluminum and copper deformed in torsion.

[1] Patterson and Orowan, Nature **162**, 991 (1948).

L9. X-Ray Analysis of Clays for Quantity of Montmorillonite. L. H. SIMONS,[1] D. F. WEEKES, AND J. G. POTTER, *A. and M. College of Texas.*—The crystalline structure of montmorillonite, $(Al_2O_3, Fe_2O_3, 3MgO)\cdot 4SiO_2 + nH_2O$, is laminar, permitting water to penetrate between unit layers, and add to the structure in a stepwise manner, sometimes to the extent that the volume is increased by a factor of thirty. The characteristically large variation in basal spacing with moisture permits the positive identification of montmorillonite by x-ray diffraction methods but has made difficult its quantitative determination by such methods. No other satisfactory method for the quantitative analysis of montmorillonite in clays is known. A sequence of treatments has been developed in this laboratory whereby the basal spacing of montmorillonite in clays can be stabilized to an extent that quantitative analyses can be made with a Geiger counter recording x-ray diffraction spectrometer. The treatments involve calcium saturating the sample, dehydration, and then bringing the sample to a reproducible moisture content in a humidifier employing sodium tartrate as the humidifying agent.

[1] Now at Humble Research Laboratory.

L10. On the Vibrational Spectrum of Crystals. W. A. BOWERS, *University of North Carolina.*—A formula has been derived for the distribution of frequencies of transverse vibrations of a plane square lattice, with nearest and next-nearest neighbor interactions. Although this case is of no direct physical significance, it is interesting as a check on the various methods of approximating the crystalline frequency distribution which have been proposed. We find that the numerical methods used by Blackman,[1] and later by Fine, Leighton, and others give a good approximation; the method of Montroll,[2] which is based on a calculation of the moments of the distribution function, also gives a reasonable approximation; but the method recently proposed by Houston[3] introduces spurious peaks into the distribution function which seriously distort its shape. We find also that in this two-dimensional case, the only peak in the distribution diverges only logarithmically instead of in the inverse square root fashion found in the linear chain. In the case of a three-dimensional crystal with vibration into a fourth dimension or degree of freedom (physical nature unknown!) we find no infinities at all.

[1] M. Blackman, Proc. Roy. Soc. **148**, 365, 384 (1935).
[2] E. Montroll, J. Chem. Phys. **10**, 218 (1942); **11**, 481 (1943).
[3] W. V. Houston, Rev. Mod. Phys. **20**, 161 (1948).

L11. Studies of the Vibrational Characteristics of a Piezoid.* CHARLES R. MINGINS, CARL A. STEVENS, AND DAVID W. MACLEOD, JR., *Tufts College.*—The characteristics of a vibrating piezoelectric crystal are investigated by means of a system of applying mechanical constraints to the surfaces with a probing device, meanwhile observing the variations produced with a response spectrometer. Different manners of mounting the plate and of providing the exciting field require different arrangements for scanning with the probing mechanism. Many modes of the thickness-shear family for rotated-Y cuts of quartz have been studied by this method. The 1,1,3 and 1,3,1 modes of this family are generally found to be very pronounced, but the coupling of these with other modes, such as certain of the higher orders of face shears and $X_{y'}$ flexures, does not have any appreciable effect upon the functioning of the principal mode. Plates of various shapes have been studied, and different cuts are receiving attention. Other methods of investigation are used to supplement and to check the results.

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

L12. Dynamic Measurement of Electro-optic Coefficients in ADP Crystals. R. O'B. CARPENTER, *Baird Associates, Inc.*—Both the electro-optic coefficients r_{41} and r_{63} in ammonium dihydrogen phosphate crystals have been measured as a function of wave-length. Although r_{63} has been measured in several tetragonal crystals by various workers, r_{41} has not been observed, except by Dr. Hans Jaffe of the Brush Development Company of Cleveland, because the small effect is largely masked by the natural birefringence. Under a field in the x direction of 6 kv/cm, the "fast" and "slow" directions of vibration are rotated 5×10^{-4} radian, while the change in n_1-n_2 is a very small effect proportional to the square of the field. By applying an alternating field to a crystal in a suitably arranged polarimeter, the rotation of the vibration direction introduces a small modulation in the transmitted light intensity, which is detected by a photo-cell and sharply tuned amplifier. The equipment is capable of detecting a rotation of 10^{-7} radian, or, in a different optical arrangement, a retardation change of 10^{-7} wave, which is considerably more sensitive than visual optical compensator methods. Other crystals are being obtained for measurement and a program of frequency response measurements is being undertaken. The coefficient e_{63} in ADP measured at frequencies above the piezoelectric fundamental vibration frequency is about one-half the low frequency value. The difference is accounted for by the piezoelectric deformation at low frequencies and the photoelastic effect, using the presently accepted values for these coefficients.

Cosmic Rays; Nuclear Emulsions

P1. Cosmic-Ray Variations at High Altitudes Resulting from Meteorological Variations.* W. F. G. SWANN AND STEPHEN H. FORBES, *Bartol Research Foundation.*—K. M. Kupferberg has called attention to latitude and seasonal variation of cosmic-ray intensity resulting from variations of the distance between the layer of mesotron production and the place of observation, which distance operates through mean-life on the cosmic-ray intensity. We have developed an expression for the percentage change of intensity at any altitude resulting from unit change in the aforesaid distance, this expression taking into account the energy distribution function and the lower limit of energy as determined by the energy necessary to penetrate the apparatus. Data supplied by the Weather Bureau show that observations extending over a single day may experience a change of 100 meters or even more in the aforesaid distance. Our calculations show that with a change of 100 meters at an altitude of 30,000 ft. with a lower energy limit determined by 9 cm of lead, the effect on the

cosmic-ray intensity amounts to 2.1 percent. With a lower limit determined by 18 cm of lead, the effect is 1.8 percent.

* Assisted by the Joint Program of ONR and AEC.

P2. Penetrating Power of Extensive Shower Particles.* L. D. WHITE, G. G. HARRIS, AND GEORGE T. REYNOLDS, *Princeton University.*—Previously reported experiments[1] to measure the absorption in load of particles associated with sea level extensive cosmic ray showers have been continued. In these experiments an extensive shower is selected by means of master coincidence trays of Geiger counters separated by a distance of about 4.5 meters. This master coincidence gates 6 other channels of Geiger counter trays under various thicknesses of lead, so that several lead thicknesses can be investigated simultaneously. A cloud chamber was placed on top of 11 inches of lead over one of the counter trays, and some pictures were obtained of the particles which might have tripped these counters. The absorption curve obtained for the extensive shower particles agrees well with the earlier results[1] and the recent results of Cocconi.[2] The fraction of particles able to penetrate 11 inches of lead is found to be 0.018 ± 0.005.

* Supported by joint program of ONR and AEC.
[1] Reynolds and Hardin, Phys. Rev. **74**, 1549 (1948).
[2] Cocconi, Tongiorgi, and Greisen, Phys. Rev. **75**, 1063 (1949).

P3. The Positive Excess in the Mesotron Spectrum.* ROBERT B. BRODE, *University of California, Berkeley.*—A Geiger counter experiment has been devised that measures the number of positive and negative particles in the energy band between 1.4 and 2.0 Bev. The particles are deflected through two feet of iron in which a field of 14,000 gauss is maintained by Alnico permanent magnets. The field in the Alnico blocks is reversed at regular intervals and the entire apparatus inverted at other intervals. By either of these procedures the sensitivity of a counter system to positive or negative particles is interchanged. The apparatus, operated at an elevation of 100 meters above sea level, has given 1.37 ± 0.04 as the ratio of positive to negative particles. This is appreciably higher than the value of 1.20 ± 0.04 given by previous[1] Geiger counter observations.

* Assisted by the joint program of ONR and AEC.
[1] Bernardini, Conversi, Pancini, Scrocco, and Wick, Phys. Rev. **68**, 109 (1945).

P4. Examples of Meson Production and Absorption.* R. L. COOL, E. C. FOWLER, AND J. C. STREET, *Harvard University.*—An 18-inch cloud chamber containing 3 lead plates, about 1 cm each, and 8 aluminum foils, 0.020 cm thick, has been operated for five months at Climax, Colorado (11,200 ft.). Some 24,000 expansions have been photographed, 7,000 random, 12,000 anti-coincidence for stopped mesons, and 5,000 with a simple shower selector. Particles in the lower energy range can, in many cases, be identified by study of the ionization, range and scattering. Five interactions have been observed in which, it is believed, mesons were produced. One of these is believed to show 2 mesons from one center. Twenty-three cases of mesons stopping in the thin foils have been identified. Of these, 10 show decay electrons, 12 show no additional track at the end point, one has a dense track coming back from the end point and stopping in the adjacent foil. The frequency of these events, not selected by counters, is in reasonable agreement with photo-plate data.

* Assisted by the joint program of ONR and AEC.

P5. Spontaneous Decay Rate of Heavy Mesons. L. I. SCHIFF, *Stanford University.*—The assumption[1] of direct interactions between nucleons and light mesons (μ), and between nucleons and electrons (e), leads to heavy meson (π) decay as a second-order process through the intermediate nucleon field, quite apart from any direct $\pi-\mu$ or $\pi-e$ coupling. The computed probabilities for both decay processes diverge in the same way. If the divergent integrals are cut off in the relativistic region, the computed life times have the order of magnitude but are somewhat shorter than the observed life time for $\pi-\mu$ decay. The ratio of the computed life times for $\pi-\mu$ and $\pi-e$ decay does not involve the divergent integral, and is approximately equal to four. This seems to disagree with experimental results at Berkeley, in which few if any $\pi-e$ decays are observed. Thus if the direct couplings of nucleons with μ and e are accepted, one must (1) also postulate a direct $\pi-\mu$ coupling, and (2) so interpret the divergent integrals that they are much smaller than they are when the relativistic cut off is used.

[1] J. Tiomno and J. A. Wheeler, Rev. Mod. Phys. **21**, 153 (1949).

P6. High Energy Events at High Altitude.* J. HORNBOSTEL AND E. O. SALANT, *Brookhaven National Laboratory.*—At 93,000 feet, production of many-pronged stars in nuclear emulsions at 31° geomagnetic latitude (cut-off 8 Bev) is about 0.3 production at 57°. Cross section for disintegration of Ag and Br nuclei by primaries is 0.5 (± 0.3) of geometrical cross section. On minimum ionization plates (Eastman NTB3), about 40 percent of these show, in addition to customary heavy, unoriented tracks, a broom-like bundle of relativistic particles fanning out downwards. In many of such broom events, the star has a single minimum ionization track in the hemisphere above it; this track is consistent in energy and location with being due to the incident particle. The broom consists, on the average, of 5 (but sometimes as high as 15) light tracks, within a cone of 120°; two-thirds of these tracks have true minimum ionization. Reasons for regarding the collimated events, in part at least, as creation of fast mesons by primaries of energy greater than cut-off are presented. We particularly thank ONR and officers and men of USS Saipan.

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

P7. Measurements and Interpretation on the "Showers" Associated with Stars in Nuclear Emulsions.* L. S. OSBORNE AND B. T. FELD, *Massachusetts Institute of Technology.*—In Eastman NTB3 emulsions, exposed as described in the previous abstract, an appreciable fraction of the nuclear disintegrations emit, in addition to the isotropically distributed, low energy evaporation products, a group (shower) of particles of relativistic energies, confined within a relatively narrow cone of angles in the downward direction. We have observed, in one star, 18 fast particles within a cone of 63° apex; 15 lie within 33°. In this event, the "cone" is really a "whiskbroom," of maximum angle quoted above. The spread along the minor axis is 10–15°. Of the 18 particles, 11 have grain densities corresponding to minimum ionization. The largest grain density corresponds to a kinetic energy of ~ 0.2 rest energy. It can be shown that the "slow" particles are certainly not electrons. Other showers studied have smaller multiplicity and do not show the "whiskbroom" effect. Measurements of multiplicity, angular spread, and grain counts have been made on a number of such showers. Evidence concerning the nature of the shower particles will be discussed. An interpretation of the data is attempted on the basis of the assumption that a shower results from a nucleon-nucleon collision, in which the nucleons lose most of their kinetic energy (in the cm system) by the multiple production of π-mesons.

* Assisted by the joint program of ONR and AEC.

P8. Energy Degeneration of Cosmic-Ray Primaries. F. J. MILFORD AND L. L. FOLDY, *Case Institute of Technology.*—Under the assumption that a meson-producing collision be-

tween two nucleons at relativistic energies is completely inelastic and that the cross-section is independent of energy, one may calculate the energy degeneration of the primary cosmic rays (assumed to be protons) and the energy spectrum of the high energy nucleons as a function of the depth in the atmosphere for any primary spectrum. Binding of nucleons into nuclei is neglected except for the "shadow effect" on the mean-free-path. An analytic solution is readily obtained for the energy spectrum as a function of depth for kinetic energies greater than 1 Bev, where ionization energy loss is negligible, and $v \simeq c$. For an incident power law differential energy spectrum $N(E) = kE^{-s}$, the same power spectrum is preserved for energies $E \gg t^{1/(s-1)} - 2$ where t is the depth in mean-free-paths, but deviations toward greater populations occur for energies below this limit. Calculations are in progress for an incident power law energy spectrum with low energy cut-off to represent the geomagnetic cut-off. Measurements of the energy spectrum of nucleons in the energy range from 1 Bev. to the geomagnetic cut-off at various depths should provide a fairly sensitive test for the postulated assumptions concerning meson-producing collisions.

P9. Rotating Illumination Method of Locating Stars in Nuclear Track Plates.* E. H. LAND AND W. A. SHURCLIFF, *Polaroid Corporation.*—Stars are usually found by bright-field microscope method affording limited field of view and requiring continual focusing up and down. Ordinary dark-field illumination fails due to background scattering by fog grains. A rotating-azimuth planar illumination scheme has been developed which provides good contrast for finding stars in emulsions whose fog background is not excessive. The dark-field illuminating rays, roughly in a single vertical plane, are 20° to 45° from the vertical and intersect in the horizontal emulsion. Tracks perpendicular to the illuminating plane gleam; others are almost invisible. As the illuminating plane rotates at 1 r.p.s. all tracks gleam successively. Magnification as low as 50× is permissible, affording a field of 3 mm diameter. Since effective depth of field is roughly 100 microns, continual focusing is unnecessary even for 200-micron emulsions. The nuclear track group at Brookhaven has not found the method applicable to differentiating tracks of different type or to locating individual tracks in very foggy emulsions, but reports five-fold faster locating of stars in favorable cases of minimum ionization plates.

* Work performed under contract with Brookhaven National Laboratory.

P10. Background Eradication of Thick-Layered Nuclear Emulsions. M. WIENER, *National Bureau of Standards* AND H. YAGODA, *National Institute of Health.*—A method for eradicating accumulated background on Ilford C-2 Plates, 100–200 microns thick without reducing their sensitivity to medium ionizing particles is described. The method involves a mild oxidation of the emulsion by air saturated with water vapor at 35°C for a period of about 16 hours. The plates are then dried and are ready for experimental exposure. Analysis of grain counts shows no loss of sensitivity in proton tracks over their last 200 microns range when the plates are developed with a mild hydroquinone developer. Complete eradication of background alpha tracks and stars is secured as well as destruction of latent images of the less ionizing proton recoils instigated by external neutron bombardment. Grain density studies on proton tracks located at different depths in the emulsion indicate substantially uniform sensitivity after eradication except for the uppermost 50 microns which develop with about a 10 percent reduction in mean grain density as compared with tracks deep within the recording medium.

Metal Physics

Q1. Electronic Phase Transition in Iron at Extreme Pressures. W. M. ELSASSER AND I. ISENBERG, *University of Pennsylvania.*—Bridgman[1] found a pronounced phase transition in metallic cesium at 45000 atm. Compression up to this point is $V/V_0 = 0.51$; in the transition $\Delta V/V_0 = -0.056$. According to Sternheimer's theory[2] the valence electron changes here from the $6s$ to a $5d$ orbital. There are theoretical indications that similar transitions occur in other metals at pressures well beyond laboratory range. There exists, *inside* the earth's core, a well established seismic discontinuity at $p = 3.1 \cdot 10^6$ atm. V/V_0 and $\Delta V/V_0$ are known with moderate accuracy; they are similar to those in Cs. Interpretation, if any, has been *ad hoc*, as a transition between liquid and solid iron. We find that a $4s - 3d$ electronic transition leaving iron in a $(3d)^8$ configuration might lead to a quite satisfactory explanation. So far the theoretical data are rather crude and do not as yet permit the quantitative identification toward which we are working. The difficulties of interpreting the discontinuity are very serious on the other hand, if one abandons the current assumption that the main constituent of the core is iron throughout.

[1] P. W. Bridgman, Proc. Am. Acad. Arts Sci. **76**, 55 (1948).
[2] R. M. Sternheimer, Phys. Rev. **75**, 888 (1949); detailed paper in print.

Q2. Martensitic Transformations in Iron-Nickel. ANDREW W. MCREYNOLDS, *Brookhaven National Laboratories.*—Transformations of crystal structure in solids occur either by a diffusion growth process or by a martensitic transition, characterized by practically instantaneous formation of plates of the new phase. Electrical and direct visual observations on Fe-Ni 71-29 alloys have been made in connection with studies of effects of strain on the transformation, and show that: (1) Quenching to a temperature in the range below −30°C results in instantaneous partial transformation followed by isothermal transformation for several minutes at decreasing rate, approaching an amount characteristic of temperature. (2) Such isothermal transformation following quenching continues at any temperature up to 20°C. The martensitic character of the isothermal transition has been verified by visual observation of the formation of plates during reheating. (3) During continuous cooling, transformation occurs initially in large steps, each representing transformation of an appreciable fraction of the total volume, and each being accompanied by instantaneous appearance of large complexes of many plates extending across many grains. Subsequent transformation occurs as smaller complexes or individual needles in the remaining interstices.

Q3. Surface Impedance of Metals at 24000 Mc/sec.* W. B. NOWAK AND J. C. SLATER, *Massachusetts Institute of Technology.*—The skin conductivity Σ,[1] of copper, silver, tin, and lead has been measured at 24000 Mc/sec. from 300°K to 4°K, and follows the theory[2] qualitatively. Surface roughness, rather than cold work, oxide layers, etc., largely accounts for low absolute values of Σ, particularly at low temperatures, and no essential disagreement with theory is found that is not explicable by roughness. Low temperature asymptotic values of Σ (in mhos) are: 93.5 for the best copper surface, 61.8 for electropolished copper, 59.8 for electropolished silver, 68.4 for tin cast against glass, and 46.5 for finely machined lead. A semi-theoretical surface roughness correction factor, applied to Σ, raises the values to 103.4 mhos for the best copper, 89.6 for electropolished copper, 74.8 for electropolished silver, and 88.4 for lead. The value of Σ for tin agrees well with unpublished results of I. Simon at 9000 Mc/sec., thus checking the theoretical frequency dependence of Σ. Computed values for the number of free electrons per atom are discussed.

* This work has been supported in part by the Signal Corps, Air Materiel Command, and ONR.
[1] A. B. Pippard, Proc. Roy. Soc. **A191**, 385 (1947).
[2] G. E. H. Reuter and E. H. Sondheimer, Proc. Roy. Soc. **A195**, 336 (1948).

Q4. Lattice Energy, Lattice Constant and Compressibility of Metallic Copper and Silver. THOMAS P. MERRITT AND ROYAL M. FRYE, *Boston University.*—A careful investigation of previous quantum mechanical treatments of lattice energy, lattice constant and compressibility of metallic copper and silver has been made. Serious discrepancies prompted a renewal of calculations, the results of which indicate the error to exist in the previous calculations for copper. The results of the present work together with earlier investigations and experimental determinations are given in Table I.

TABLE I

	Cohesive energy	Lattice constant	Compressibility
	Copper		
Theoretical (as determined in this work)	112 kg cal./mole	1.98A	0.0082×10^{-11} cm²/dyne
Experimental	71.0	3.6	0.070×10^{-11}
K. Fuchs (Reported)	34.1	4.2	0.069×10^{-11}
(From his graphs)	34.1	4.6	0.545×10^{-11}
	Silver		
Theoretical (as determined in this work)	71.8 kg cal./mole	2.57A	0.035×10^{-11} cm²/dyne
Experimental	64.5	4.03	0.090×10^{-11}
R. C. Gunter	95.8	2.72	(0.056×10^{-11})

Q5. Elastic Constants of Single Crystals of Nickel. W. P. MASON, R. M. BOZORTH, H. J. MCSKIMIN, J. G. WALKER, *Bell Telephone Laboratories.*—Measurements have been made of the elastic constants of nickel, using two specimens of single crystals grown by slow cooling of the melt. Planes were cut parallel to (100) and (110) within less than one degree as determined with x-rays. Thin crystals of quartz were cemented to these surfaces and velocities of elastic waves determined by pulsing methods. In a more satisfactory arrangement two fused silica rods were fastened to opposite sides of a nickel crystal with the interposition of polystyrene films a quarter wave-length thick, and quartz crystals were placed at the other ends of the rods. The longitudinal or shear wave excited by one of the crystals was reflected multiply in the nickel and detected by the other crystal. The pulses were made longer than the time between reflections and the pulsing frequency adjusted until all pulses added in phase, and the velocity then calculated from this frequency. Results are: $c_{11}=2.50$, $c_{12}=1.60$, $c_{44}=1.185$, all times 10^{12}. The anisotropy factor, $2c_{44}/(c_{11}-c_{12})$, is 2.63. In the longitudinal [100] wave at 10 Mc/sec., $Q=300$. The decrement (π/Q) increases approximately as f, indicating magnetic damping from micro eddy currents.

Q6. Strain Rate Effects in Polycrystalline Cadmium Wire. RICHARD LATORRE AND WALLER GEORGE, *Naval Research Laboratory.*—The strength of polycrystalline high purity cadmium wire (".005 diameter) strained at controlled rates from 10^{-6} to 10^{-2} sec.$^{-1}$ shows a rapid increase for true strain rates between $10^{-5}-10^{-3}$ sec.$^{-1}$. Through this region the rupture load varies from approximately 20 g to 60 g. Load-strain curves show, in general, a region from small to medium "homogeneous" strains where the load resisting deformation remains essentially constant. For larger strains, at strain rates greater than 10^{-3} this load increases with strain. For strain rates below 10^{-5} the load drops with increasing strain. The time during which the resistant load is essentially constant varies from about 20 sec. at strain rates of 10^{-3} to about 2400 sec. at 10^{-5} sec.$^{-1}$. The former time is, to order of magnitude comparable, to the "incubation times" recently reported by Wood for mild steel.[1] Our data suggest that the nucleation mechanisms in cadmium for strain softening may be different from those for strain hardening (work hardening). Other features of the stress-strain relationship at constant true straining rates appear quite analogous to those obtained for single crystals.[2,3]

[1] D. S. Wood, Second Symposium on Plasticity, Brown Univ., April 1949.
[2] E. N. da C. Andrade and R. Roscoe, Proc. Phys. Soc. (London) **49**, 152 (1937).
[3] W. Boas and S. Schmid, Zeits. f. Physik **54**, 16 (1929); *ibid.* **61**, 767 (1930).

Q7. Anomalous Internal Friction Associated with the Precipitation of Cu in Plastically Deformed Al-Cu Alloys. T'ING-SUI KÊ, *University of Chicago.*—Anomalous internal friction at small stress levels has been observed in plastically deformed aluminum-copper alloys heat-treated short of complete recrystallization. The temperature range within which such anomalous internal friction was observed is −5 to 125°C in the case of aluminum specimens containing ½ percent of copper. At each temperature within the range, the anomalous effect first increases and then decreases with the aging time at that temperature. This effect is shown to be associated with the precipitation of Cu from the solid solution with aluminum. It seems to be correlated with the well-known phenomena of precipitation hardening except that it proceeds at a much faster rate. The internal friction associated with this effect is anomalous in the following aspects: (1) At a given temperature, it first increases and then decreases with decreasing stress amplitude; (2) the value of internal friction at a given temperature is temporarily reduced by previous vibration. The frequency of vibration used was about one cycle per second in torsion and the maximum shearing strain on the specimen was about 10^{-5}. The physical origin of this internal friction and its implications will be discussed.

Q8. The Increase in the Resistivity of Ordered $AuCu_3$ Produced by Single Slip. T. H. BLEWITT* AND J. S. KOEHLER, *Carnegie Institute of Technology.*—Single crystals of $AuCu_3$ were produced in a high vacuum by the Bridgman method using 99.999 percent pure copper and gold. The tensile specimens of ⅛" diameter (ASTM specifications) were homogenized and ordered. The electrical resistances were measured potentiometrically from 90 to 300 degrees absolute. Residual resistances were obtained by fitting Gruneisen's equation using Matthiesson's rule. It was found that the characteristic temperature of the undeformed specimens was 275 degrees with a residual resistance of 1.36 micro-ohm centimeters. Upon deformation the residual resistance does not change; for a bicrystal, at 30 percent shear strain (15 percent elongation) the residual resistance changes by about 1 percent with no change being apparent in the characteristic temperature. Dahl[1] deformed polycrystals and obtained much larger resistance changes. The stress-strain curves obtained were in substantial agreement with those of Sachs and Weerts.[2] Calculations made using Taylor's theory of deformation and a variation of Muto's treatment of the resistance of disorder gave resistance changes many times larger than those observed.

* AEC Fellow in the Physical Sciences. Supported by ONR.
[1] O. Dahl, w. Metallkunde **28**, 133 (1936).
[2] G. Sacks and J. Weerts, Zeits. f. Physik **67** (1931).

Q9. Grain Boundary Diffusion. M. R. ACHTER AND R. SMOLUCHOWSKI, *Carnegie Institute of Technology.*—One of the least known parts of a polycrystalline material is its grain boundary. As an indication of the degree of perfection of and the mobility of atoms in, the boundary layer, diffusion along the grain boundaries is being studied by means of x-ray, electrographic, and microscopic methods. Preliminary results indicate that the rate of diffusion is influenced by the relative orientations of the two grains forming the boundary. This behavior would be predicted from a study of a rough model of a grain boundary, and agrees with the fact that a grain boundary between two fixed grains has a preferred orientation

of lowest energy. From the rough data, it has been possible to obtain a comparison of the rates of grain boundary diffusion to the rates of volume diffusion in the case of silver diffusing into copper. This estimate, made on copper in which all grains had one cubic axis almost parallel to the direction of diffusion, indicates that the activation energy for the grain boundary diffusion is 20,000 calories smaller than that for the volume diffusion.*

* Work done under contract with the AEC.

Q10. Mechanism of Ordering in Co-Pt. J. B. NEWKIRK AND R. SMOLUCHOWSKI, *Carnegie Institute of Technology.*—As part of a study of the influence of order on magnetic properties, a detailed investigation of atomic ordering in the ferromagnetic Co-Pt (50-50) alloy is being continued.* X-ray studies are being made on powders and single crystals. The results show that ordered and disordered phases can coexist, thus indicating that the reaction is of a heterogeneous character. It is believed that at least with the tetragonal type ordered lattice this is a general characteristic, all indications to the contrary being due to the inadequacy of the experimental methods. The structure of the surface material appears to influence the critical temperature of that layer or the rate at which the ordering reaction can take place there. Microscopic evidence indicates the existence of a fine structure within the grains which resembles polygonalization or mosaic structure observed in pure metals. A possible relation of this structure to order is considered. Single crystal work shows the presence of lattice strains and aperiodic regions (order-disorder layers) which are parallel to the (111) planes. This is in agreement with the minimum strain condition of the tetragonal ordered structure.

* Work done under contract with the AEC.

Q11. Magnetostriction and Order in $FeNi_3$. J. E. GOLDMAN, *Westinghouse Research Laboratories.*—The magnetostriction of the alloy $FeNi_3$ was measured as a function of the state of order. The strain gauge technique previously described was employed for this purpose.[1,2] Samples of the 76.5 percent nickel vacuum melted alloy $3\times3\times0.05$ cm were cut and measurements were made in both long directions in order to eliminate errors due to the possible non-randomness of the initial domain distribution. The ordered samples were heated to 600°C for 24 hours and then cooled through the critical temperature at the rate of 2°C per hour to 300°C. The disordered samples were measured in the cold worked state after a cold reduction of 75 percent. The saturation magnetostriction is found to increase by more than 100 percent on ordering. The magnitude of the magnetostriction in the cold worked sample is 1.9×10^{-6} and in the annealed sample is 4.15×10^{-6}. The latter value is in closer agreement with the value reported by various investigators for an alloy of this approximate composition which may indicate that most of these investigators employed at least partially ordered samples.

[1] J. E. Goldman, Phys. Rev. **72**, 529 (1947).
[2] J. E. Goldman and R. Smoluchowski, Phys. Rev. **75**, 140 (1949).

Q12. Rate of Self-Diffusion in Single and Polycrystals of Silver.* D. TURNBULL, *General Electric Research Laboratory.*—At comparatively high temperatures (800–950°C) the self-diffusion coefficients, D, in single and polycrystalline silver specimens were found in good agreement with those measured by Johnson[1] on large-grained silver specimens. In the low temperature range (500–600°C) D for single crystals agreed closely with the values calculated from the relation valid at high temperatures which was: $D=0.90\exp(-46{,}000/RT)$ cm^2 $sec.^{-1}$. Also in this temperature range D for single crystals slow-cooled from high temperatures agreed, within experimental errors, with D for single crystals rapidly cooled from high temperatures. The apparent D for fine-grained silver (mean linear grain dimension = 1.36 mils.) was much larger than for single crystals in the low temperature range and followed the relation: $D=2.3\times10^{-5}\exp(-26{,}100/RT)$.

* This work was sponsored by the Research Division of the AEC.
[1] W. A. Johnson, Trans. A.I.M.E. **143**, 107 (1941).

Molecular Spectra, Mostly Microwave

R1. Rotational Magnetic Moments for H_2O and HDO. C. K. JEN, *Harvard University.**—The rotational g-factors for H_2O and HDO have been studied by observing the Zeeman splitting of their rotation lines in the microwave spectrum. For the σ-components of the $5_{-1}-6_{-5}$ line of H_2O (22,235.22 mc/sec.), the Zeeman splitting resolved into a doublet pattern for a field as low as 300 oersteds. The doublet separation was found to be a linear function of the field except that each doublet component became continuously weaker and broader with increasing field and was hardly recognizable beyond 2500 oersteds. The measurement gave for this line $g'=h\Delta\nu/\beta H_0=0.586\pm0.012$, where $\Delta\nu$ = frequency displacement of each doublet component, h = Planck's constant, β = nuclear magneton, and H_0 = magnetic field. The Zeeman patterns for the $4_{-3}-3_1$ line (20,460.40 mc/sec.) and the 5_0-5_1 line (22,307.67 mc/sec.) of HDO were similar to that of the above-mentioned H_2O line as regards doublet appearance and linearity with magnetic field. However, the 5_0-5_1 line showed a sharp doublet pattern for fields as high as 7000 oersteds, whereas the $4_{-3}-3_1$ line pattern became unrecognizably diffuse for fields above 3000 oersteds. The measured g'-values for HDO lines are $g'(4_{-3}-3_1)=0.413\pm0.008$ and $g'(5_0-5_1)=0.465\pm0.009$. It is noteworthy that the ratio of $g'(H_2O)$ to $g'(HDO)$ is close to the ratio of the reduced mass $\mu(HD)$ to $\mu(H_2)$. This suggests that the rotation of the hydrogen or deuterium atoms contributes a large proportion of the molecular g-factor for a water molecule.

* Supported by ONR contract.

R2. On the Limits of Validity of the Van Vleck-Weisskopf Line Shape Formula.* P. W. ANDERSON, *Bell Telephone Laboratories.*—By use of the Einstein relations the line shape in gaseous absorption can be derived rigorously from that for spontaneous emission, $I(\nu)$. $I(\nu)$ is given, if the translational motion of the emitting molecules can be assumed to be classical, by the well-known Fourier integral formula or by a more rigorous variation thereof derived by the author.† The solution of either type of Fourier integral for sufficiently low pressures is the standard dispersion line shape. The Einstein relations applied to the correct dispersion shape give the Van Vleck-Weisskopf line shape at microwave frequencies. The conditions under which this line shape fails can be two-fold: either the low-pressure solution of the Fourier integral fails, or the classical treatment of translational motion becomes invalid. Reasons are advanced which indicate that the latter is always the case at frequency differences from the line center of greater than kT/h.

* J. H. Van Vleck and V. F. Weisskopf, Rev. Mod. Phys. **17**, 227 (1945).
† Unpublished.

R3. The Radiofrequency Spectrum of $Rb^{85}F$ and $Rb^{87}F$. VERNON HUGHES, LUDWIG GRABNER, AND I. I. RABI, *Columbia University.*—The radiofrequency spectrum of $Rb^{85}F$ and $Rb^{87}F$ had been studied by the molecular beam electrical resonance method.[1,2] The main features of the spectrum for either isotope are predicted from a Hamiltonian:[2,3]

$$H=+\frac{\hbar^2}{2A}\mathbf{J}^2-\boldsymbol{\mu}\cdot\mathbf{E}-\frac{e^2q_1'Q_1}{I_1(2I_1-1)(2J-1)(2J+3)}\times\{3(\mathbf{I}_1\cdot\mathbf{J})^2+\tfrac{3}{2}(\mathbf{I}_1\cdot\mathbf{J})-\mathbf{I}_1^2\mathbf{J}^2\}.$$

However, a splitting of the lines is observed, which suggests that a small interaction of the form $c_2 I_2 \cdot J$ be added to this Hamiltonian.[2,3] (I_2 is spin of F.) The data are:

		$\lvert e^2q_1'Q_1\rvert$	
		$Rb^{85}F$	$Rb^{87}F$
J	V	(mc/sec.)	(mc/sec.)
1	0	35.158±0.06	17.000±0.02
1	1	34.772±0.06	16.814±0.02
1	2	34.358±0.06	16.600±0.02
1	3	33.997±0.06	
1	4	33.597±0.06	

where J=rotational quantum number, V=vibrational quantum number, $e^2q_1'Q_1$=quadrupole interaction constant of Rb in RbF. An "extra" line was observed and is tentatively believed to be a two-quantum process.

[1] H. K. Hughes, Phys. Rev. **72**, 614 (1947).
[2] J. W. Trischka, Phys. Rev. **74**, 718 (1948).
[3] W. A. Nierenberg *et al.*, Phys. Rev. **73**, 1430 (1948).

R4. The Radiofrequency Spectrum of $K^{39}F$. LUDWIG GRABNER, VERNON HUGHES, AND I. I. RABI, *Columbia University.*—The radiofrequency spectrum of $K^{39}F$ has been studied by the molecular beam electrical resonance method.[1,2] The Hamiltonian is:[3]

$$H=+\frac{\hbar^2}{2A}\mathbf{J}^2-\boldsymbol{\mu}\cdot\mathbf{E}-\frac{e^2q_1'Q_1}{I_1(2I_1-1)(2J-1)(2J+3)}\times\{3(\mathbf{I}_1\cdot\mathbf{J})^2+\tfrac{3}{2}(\mathbf{I}_1\cdot\mathbf{J})-\mathbf{I}_1^2\mathbf{J}^2\}.$$

The data are:

		$-e^2q_1'Q_1$
J	V	(mc/sec.)
1	0	3.969±0.02
1	1	3.914±0.02
1	2	3.872±0.02
1	3	3.829±0.02
2	0	3.964±0.02
2	1	3.914±0.02
2	2	3.863±0.02

where J=rotational quantum number, V=vibrational quantum number, $e^2q_1'Q_1$=electrical quadrupole interaction constant of K^{39} in $K^{39}F$.

[1] H. K. Hughes, Phys. Rev. **72**, 614 (1947).
[2] J. W. Trischka, Phys. Rev. **74**, 718 (1948).
[3] W. A. Nierenberg *et al.*, Phys. Rev. **73**, 1430 (1948).

R5. The Molecular Structure and Dipole Moment of Chlorosilane.* B. P. DAILEY, J. M. MAYS, AND C. H. TOWNES, *Columbia University.*—Three previously unreported lines arising from the $J=1\rightarrow2$ rotational transitions of the rarer isotopic species of chlorosilane, $Si^{29}H_3Cl^{35}$, $Si^{29}H_3Cl^{37}$, and $Si^{30}H_3Cl^{35}$, have been observed. The transitions involving Si^{29} are being studied further. The accurately measured $Si^{30}H_3Cl^{35}$ frequency combined with those of Sharbaugh[1] gives the following values of Bo in Mc/sec.=$Si^{28}H_3Cl^{35}$, 6,673.8; $Si^{28}H_3Cl^{37}$, 6,512.4; $Si^{30}H_3Cl^{35}$, 6,485.8. From these data, the molecular parameters, uncorrected for zero-point vibrations, Si-Cl distance 2.05A, Si-H 1.50A, and H-Si-H angle 110° 57′, are obtained. These are to be compared with the previous values[1] 2.035A, 1.456A, and 103° 57′, respectively. The new H-Si-H angle is seen to be slightly larger than the tetrahedral angle of 109° 28′, and very close to the values reported for the methyl halides by Gordy.[2] In addition, measurement of the Stark displacement of the $J=1\rightarrow2$, $F=5/2$, $7/2$, $K=1$ line of $Si^{28}H_3Cl^{35}$ as a function of field strength yields a dipole moment of 1.311 Debye units, as compared with the earlier value of 1.284±0.005 obtained from polarization measurements.[3]

* Work supported jointly by the Signal Corps and ONR.
[1] A. Sharbaugh, Phys. Rev. **74**, 1870(L) (1948).
[2] Gordy, Simmons, and Smith. Phys. Rev. **74**, 243 (1948).
[3] Brockway and Coop, Trans. Faraday Soc. **34**, 1429 (1938).

R6. Dipole Moments from Microwave Spectra.* C. H. TOWNES, R. G. SHULMAN, AND B. P. DAILEY, *Columbia University.*—The dipole moments of several molecules have been determined by measurements of the Stark splitting of the quadrupole components of rotational transitions in the microwave region. A Stark modulation microwave spectroscope was used and the method and calibrations have been reported.[1] On the basis of the theory of Low and Townes[2] the splittings of the first-order lines of AsF_3 and CH_3I were calculated. By selecting the transition observed it was possible to find the splitting as a solution of a second order equation. The calculations for the highest values of F and M are the simplest for these molecules and also for the second-order Stark splitting of CH_3Cl^{35} which was calculated by Fano's[3] method. In all cases the accuracy was greater than one percent. The moments of $N^{15}N^{14}O^{16}$ and CH_3CF_3 were also measured and the values given below in Debye units. $CH_3Cl^{35}\mu=1.871\pm0.005$; $CH_3I\mu=1.658\pm0.014$; $AsF_3\mu=2.834\pm0.025$; $CH_3CF_3\mu=2.35\pm0.02$; $N^{15}N^{14}O^{16}\mu=0.167\pm0.002$.

* Work supported jointly by the Signal Corps and ONR.
[1] R. G. Shulman and C. H. Townes, Phys. Rev. **75**, 1318 (1949).
[2] W. Low and C. H. Townes, Phys. Rev. **75**, 1319 (1949).
[3] U. Fano, J. Research Nat. Bur. of Stand. **40**, 215 (1948).

R7. Microwave Spectrum of Formaldehyde.* R. B. LAWRANCE, R. L. KYHL,** AND M. W. P. STRANDBERG, *Massachusetts Institute of Technology.*—H_2CO is a slightly asymmetric rotor whose absorption spectrum has been extensively studied in the infra-red[1,2] and ultraviolet.[3] The asymmetry removes the symmetric-top K degeneracy, giving a wealth of $\Delta J=0$ lines in the accessible microwave region. Bragg and Sharbaugh[4] have identified four of these pure rotation lines in the region 18,300–27,500 megacycles. We have explored the region 14,000–73,000 megacycles, with some gaps. Our measurements of the $0_{00}\rightarrow1_{01}$ line and the homologous series $2_{12}\rightarrow2_{11}\cdots5_{15}\rightarrow5_{14}$ give exceedingly accurate values of the reciprocal moments b and c. Several lines from each of the K_{-1} sequences 2, 3, and 4 have been measured and afford rather accurate centrifugal-distortion corrections. In several lines, the effective dipole moment has been evaluated by means of the Stark effect.

* This research has been supported in part by the Signal Corps, the Air Materiel Command, and ONR.
** Now at Stanford University.
[1] H. H. Nielsen, Phys. Rev. **46**, 117 (1934).
[2] E. S. Ebers and H. H. Nielsen, J. Chem. Phys. **5**, 822 (1937).
[3] G. H. Dieke and G. B. Kistiakowsky, Phys. Rev. **45**, 4 (1934).
[4] Private communication, since published in Phys. Rev. **75**, 1774 (1949).

R8. The Microwave Spectrum of Chloroacetylene and Deuterochloroacetylene. A. A. WESTENBERG, J. H. GOLDSTEIN, AND E. B. WILSON, JR.—The $J=1\rightarrow2$ pure rotational transitions in the linear molecules $H-C\equiv C-Cl^{35}$, $H-C\equiv C-Cl^{37}$, $D-C\equiv C-Cl^{35}$, and $D-C\equiv C-Cl^{37}$ have been observed using a Stark Modulation microwave spectrograph. The frequencies of the principal components (5/2→7/2) of the multiplets are 22738.6_8, 22290.8_5, 20749.7_6, and 20338.2_3 megacycles, respectively. The quadrupole hyperfine structure has been analyzed in the usual manner, yielding values for the nuclear quadrupole coupling constants of −79.67, −62.75, −79.66, and −63.12 (mc), respectively. By comparison, the values for $Cl^{35}CN$ and $Cl^{37}CN$ are −83.4 and −65.3. The observed Stark effect is in good agreement with that calculated for a linear molecule with a single quadrupolar nucleus. This leads to a calculated value for the dipole moment of 0.44 ±0.01D. The previously reported value is 0.44±0.01D. Bond distances calculated are H—C=1.052±0.001A, C—C=1.211 ±0.001A, and C—Cl=1.632±0.001A. The previously reported electron diffraction results are C—C=1.21±0.04A and C—Cl =1.68±0.04A. Both the bond distances and the quadrupole coupling constant indicate the presence of important resonating structures in the molecule.

R9. A Reinvestigation of the Vibration Spectrum of Nitrogen Dioxide. M. KENT WILSON, *Harvard University* AND RICHARD M. BADGER, *California Institute of Technology.*—The infra-red spectrum of nitrogen dioxide was investigated under

prism dispersion between 1.5 and 25μ. The weak symmetric valence vibration, heretofore unreported in the infra-red, was found near 1306 cm^{-1} and the center of the bending vibration was located near 755 cm^{-1}. This latter value is in contrast to the value of 648 cm^{-1} previously reported.[1] These observed infra-red frequencies are in good agreement with the values of 1319 cm^{-1} and 749 cm^{-1} which were found to occur in the temperature-sensitive ultraviolet bands of nitrogen dioxide.[2] Both ν_1 and ν_2 exhibit doublet structures with rotational spacing of about 15 cm^{-1}. This spacing leads to a value of A″–B″ in close agreement with that calculated for the obtuse angled structure as determined by electron diffraction.[3] Several infra-red bands ascribed to nitrogen dioxide have been shown by their temperature dependence to belong to nitrogen tetroxide.

[1] R. Schaffert, J. Chem. Phys. **1**, 507 (1933).
[2] Harris, King, Benedict, and Pearse, J. Chem. Phys. **8**, 765 (1949).
[3] Claesson, Donohue, and Schomaker, J. Chem. Phys. **16**, 207 (1948).

R10. Isotopic Frequencies in the Microwave Spectra of OCS and CH_3Cl. D. Bianco, G. Matlack, and A. Roberts, *State University of Iowa.*—Additional isotopic lines have been observed in the microwave spectra of OCS and CH_3Cl. In OCS, a sample enriched in O^{18} (kindly provided by Professor A. O. C. Nier of the University of Minnesota) yielded the following new lines:

Isotope	V_1 V_2 V_3	Frequencies of 1→2 trans.
O^{18} C^{12} S^{32}	1 0 0	22754.6 ±0.2 mc
	0 1 0	22871.28 ±0.1
	0 1 0	22848.70 ±0.1
O^{18} C^{13} S^{32}	0 0 0	22763.8 ±0.2
O^{18} C^{12} S^{34}	0 0 0	22239.6 ±0.2

The excited vibrational lines provide proof that the vibration-rotation constant α_1 varies inversely as the $\frac{3}{2}$ power of the total mass. The quadrupole coupling of the O^{17} line has been determined to be not more than 1 mc. In CH_3Cl, triplets have been observed due to the chlorine quadrupole splitting of the 0→1 transitions of $C^{13}H_3Cl^{35,37}$, $C^{12}H_2DCl^{35,37}$, and $C^{12}HD_2Cl^{35,37}$. Accurate values of the frequencies will be presented.

* Supported in part by ONR.

R11. Quadrupole Interactions in Pressure Broadening of Ammonia Inversion Spectrum by Non-Polar Gases.* William V. Smith and Raydeen Howard.—We have measured the N_2-NH_3, O_2-NH_3, and CO_2-NH_3 collision cross sections from the pressure broadening of the ammonia inversion spectrum, finding values relative to the NH_3-NH_3 cross section of 0.202, 0.115, and 0.455. The first two values check Bleaney and Penrose's values,[1] confirming the large cross section for nitrogen. The value for CO_2 may be compared with their value of 0.296 for CS_2 which, with its larger polarizability might be expected to have the larger cross section. The anomalous cross sections of N_2 and CO_2 can be explained on the assumption that these molecules have permanent quadrupole moments of, respectively, 0.06×10^{-16} and 0.29×10^{-16} cm^2. Interaction of the quadrupole and dipole, with an r^{-4} law rather than the r^{-6} law of polarizable molecules gives the required interaction energy at the observed cross section. The triple bond of N_2 with its abnormally large energy of formation suggests a high electronic density between the two nuclei—hence a quadrupole moment. The lower quadrupole moment of CS_2 compared to CO_2 is to be expected from the small difference in electronegativity of carbon and sulfur.

* The research described in this report was supported by Contract No. W-19-122-ac-35 with the Air Forces, Air Materiel Command, Cambridge Field Station.

R12. The Infra-Red Spectrum of Benzene at Liquid-Helium Temperature. R. M. Hainer and Gilbert W. King, *Arthur D. Little, Inc.*—The infra-red absorption spectrum of solid benzene has been investigated between 1200 and 660 cm^{-1} at 4°K, the temperature of liquid helium. These data were obtained with a low-temperature infra-red transmission cell recently described.[1] The sample was deposited from the gas phase and did not scatter infra-red. Bands were found at 1171 (weak), 1145 (w), 1141 (w), 1037.$_5$ (strong), 1033 (s), 1009 (medium), 986.$_5$ (m), 978 (m), 974.$_5$ (m), 706 (s), 680 (v.s.) cm^{-1}. The pairs 1145–1141, 1038–1033, 978–975 cm^{-1} appear to be frequencies degenerate in the isolated molecule, split on the average by 4 cm^{-1} by the crystalline field. Slit widths at 1160, 1000, and 700 cm^{-1} were 3.5, 2.5, and 1.6 cm^{-1} respectively. The half-widths of the bands are in all cases greater. The band at 1171 is absent at 278°K, is apparent at 60°K, then decreases in intensity as the temperature is lowered to 4°K. Recent interpretations[2–4] of the spectrum of benzene are not entirely supported by these results.

[1] McMahon, Hainer, and King, Phys. Rev. **75**, 1320 (1949).
[2] R. D. Mair and D. F. Hornig, Phys. Rev. **75**, 1283 (1949).
[3] C. K. Ingold *et al.*, J. Chem. Soc. 222 (1946).
[4] B. L. Crawford and F. A. Miller, J. Chem. Phys. **17**, 249 (1949).

R13. An Empirical Formula for the Refractive Indices of Infra-Red Dispersing Materials. Gilbert W. King, *Arthur D. Little, Inc.*—D. S. McKinney and R. A. Friedel[1] have shown the calibration curve of a Perkin-Elmer spectrometer can be expressed as a linear relation between the rotation (ϕ) of the wave-length shaft and the quantity $u=1/\nu^2-\nu_0^2$, ν_0 being the first reststrahlen. Since the conditions of dispersion are essentially those of minimum deviation, this result leads to the following empirical formula for the refractive index: $\sin^{-1}n=-k_1u+k_0$ which fits the refractive indices of the common dispersing media within 50 parts per million over the useful range in a spectrometer. For purposes of calibration of wave-length and resolving power the properties of the refracting medium are thus described completely by the single parameter k_1. The calibration curve can be written $(\phi-\phi_0)=2Gk_1u$. Here $G(=798.8)$ is the gear ratio[2] between the wave-length shaft and Littrow mirror and is independent of the prism used. Suitable values of k_1 for KCl, NaCl, CaF_2, LiF are 0.01308, 0.02414, 0.07945, and 0.160×10^6 radians cm^{-2} respectively. Calibration curves from this formula agree within experimental error of locating peaks with those obtained from measurements of known spectra.

[1] D. S. McKinney and R. A. Friedel, J. Opt. Soc. Am. **38**, 222 (1948).
[2] Obtained by private communication with Dr. Van Zandt Williams of the Perkin-Elmer Corporation.

SUPPLEMENTARY PROGRAMME

SP1. Brownian Motion in Liquids.* Frederik J. Belinfante, *Purdue University.*—A simple derivation of Einstein's equation for Brownian motion is given, in which the motion is regarded as the superposition of motions due to single collisions. Correlations between collisions are taken into account only roughly by a phenomenological friction law. For sufficiently large particles one can take Stokes' law for this. The number of thermal collisions against a particle of 0.2μ diameter is about $10^{17}\sim10^{19}$ sec.$^{-1}$, but the number of collisions giving an appreciable impulse to the particle is many times smaller, as simultaneous collisions from different directions tend to neutralize the impulses. Even thus, the number of "effective" collisions during the "relaxation time" of about $10^{-11}\sim10^{-8}$ sec. (time in which velocity is about halved by

friction) is about 10^7, and each such collision alters the velocity only slightly. Thus the actual motion is no zigzag, but is irregularly curved. For very small particles Stokes' law will break down for Brownian motion; the higher the viscosity of the liquid, the sooner this breakdown occurs. (For instance, for glycerin at room temperature, Stokes' law is already inapplicable for particles of 1μ.) Details will appear in the American Journal of Physics.

* To be presented at the end of Session B if the Chairman rules that time permits.

SP2. An Experimental Limit for the Inequality of the Electron and Proton Charges.* VERNON HUGHES, *Columbia University.*—The charge on the CsI molecule is proven to be less than 6.5×10^{-22} e.s.u. or 1.4×10^{-12} of the electronic charge by a deflection experiment on a beam of CsI molecules passing through a homogeneous electric field. This implies that the magnitude of the proton charge equals that of the electron charge to at least 1.3 parts in 10^{14}. By measurement of the charge of a mass of deionized gas, Piccard and Kessler proved that the ratio of the electron charge to the proton charge is $(-1\pm5\cdot10^{-21})$.[1]

* To be presented at the end of Session J if the Chairman rules that time permits.

[1] A. Piccard and E. Kessler, Archives des Sciences Physiques et Naturelles **7**, 340 (1925).

SP3. A Theoretical Treatment of Neutron Attenuation in Thick Shields.[1] S. W. W. SHOR, *Massachusetts Institute of Technology.**—By application of statistical sampling concepts to the Monte Carlo method, a procedure for computing neutron attenuation through very thick shields has been developed. This method allows computation of the fast flux transmitted through a thick plane shield with the aid of a desk calculator, a table of random numbers, and a table of logarithms. The equation actually being solved in the case of a plane slab is $\gamma(\partial\phi/\partial z)=-\mu\phi+\int_\mu^{\mu_0}\int_\gamma K(\mu,\mu',\gamma,\gamma')\phi d\mu' d\gamma'$. Substitution of $\Phi=\phi e^{sz}$ makes it possible to solve for e^{sz} times the actual flux through the slab. This transformation, apparently devised by Herman Kahn, and John von Neumann's "Russian Roulette" are combined to minimize variance of the transmitted flux. A sample computation was made assuming a beam of fast neutrons incident normally on a plane slab of tungsten about 25 relaxation lengths thick. The computation gave the flux transmitted after one or more collisions with a statistical probable error of less than 10 percent, and required five man-days to complete.

* This is a joint undertaking of M.I.T. and ONR.

[1] To be presented at the end of Session J if the Chairman rules that time permits.

Author Index to Papers Presented at the Cambridge Meeting