Proceedings of the American Physical Society

Minutes of the Meeting at the California Institute of Technology, Pasadena, California

THE 287th meeting of the American Physical Society was held at the California Institute of Technology, Pasadena, on June 24–26, 1948. This meeting followed the Symposium on Cosmic Rays, which was held in honor of Professor R. A. Millikan's eightieth birthday and, as a consequence, The Physical Society meeting was attended by an unusually large number of distinguished physicists from the East and from foreign lands. The Division of Fluid Dynamics presented its first Symposium on the Pacific Coast as part of the Heat Transfer and Fluid Mechanics Institute. The American Physical Society dinner was held on Friday, June 25, at the Athenaeum, with Dr. J. R. Oppenheimer presiding, and Professor and Mrs. R. A. Millikan as honored guests. About two hundred and fifty attended the dinner. Doctors Pierre Auger, G. D. Rochester, M. S. Vallarta, J. Clay, and I. I. Rabi paid tribute to Dr. Millikan's achievements during a short program following the dinner.

The opening session of the meeting attracted the largest audience of about 500. Two papers by I. I. Rabi and Julian Schwinger resulted in one of the best meetings ever held on the Pacific Coast. Dr. Millikan presided. The attendance at the other sessions varied from about 200 to 400. Outstanding invited papers attracted these large audiences. At the second session, presided over by C. D. Anderson, the speakers were E. H. Krause, Marcel Schein, and W. B. Fretter. The third session for invited papers brought together C. M. G. Lattes and E. Gardner on the experimental side of the observation of mesons in the 184-inch cyclotron, and R. Serber on the theoretical side. A fourth session was made up of papers by H. W. Babcock, A. C. Helmholz, and W. M. Powell, and the final session on problems of interest to the fluid dynamics group was made up of papers by R. W. Ladenburg and I. Estermann.

Post-deadline papers were presented by Luke C. L. Yuan on the "Neutron density in the free atmosphere up to 67,000 ft.," and by Kan-Chang Wang and S. B. Jones on the "Disintegration of cosmic-ray mesotrons."

J. Kaplan, *Local Secretary for the Pacific Coast.*

Invited Papers

A1. Recent Experiments on the Dynamics of the Electron in Atoms. I. I. Rabi, *Columbia University.*

A2. (Subject to be announced.) Julian Schwinger, *Harvard University.*

B1. Cosmic Rays above the Atmosphere. E. H. Krause, *Naval Research Laboratory.*

B2. The Problem of Low Energy Mesotrons in the Cosmic Radiation. Marcel Schein, *University of Chicago.*

B3. Penetrating Showers in Lead. W. B. Fretter, *University of California, Berkeley.*

D1. Observation of Mesons Produced by the 184-Inch Cyclotron. C. M. G. Lattes and E. Gardner, *University of California, Berkeley.*

D2. Interpretation of the Radiation Laboratory Meson Experiments. R. Serber, *University of California, Berkeley.*

E1. Stellar Magnetic Fields. H. W. Babcock, *Mount Wilson Observatory.*

E2. Nuclear Isomerism. A. C. Helmholz, *University of California, Berkeley.*

E3. Cloud-Chamber Measurements of Recoil Protons in the Neutron Beam of the 184-Inch Cyclotron. W. M. Powell, *University of California, Berkeley.*

G1. (Subject to be announced.) R. W. Ladenburg, *Princeton University.*

G2. The Interaction of Molecules with Solid Substances. I. Estermann, *Carnegie Institute of Technology.*

Contributed Papers

B4. The Altitude Dependence of Auger Showers. M. M. Mills, *California Institute of Technology.*—Assuming primary electrons, the variation of shower counting rate with altitude has been computed and compared with Kraybill's[1] observations. The theory gives a weaker maximum (ratio: maximum to sea level is 24 *vs.* 63 for experiment) at a greater depth (10.5 radiation units *vs.* 8.5 for experiment). The theoretical zenith angle distribution of showers which are detected by Kraybill's counters at 31,000 feet has been compared with one observed by E. W. Cowan utilizing a counter-controlled cloud chamber. The observed distribution has a different shape and is narrower (half-angle 17 degrees *vs.* 30 degrees for theory) than the theoretical. It is difficult to reconcile this discrepancy with the observed altitude dependence. The multiple production of secondaries by primary protons proposed by Lewis, Oppenheimer, and Wouthuysen[2] should lead to a more pronounced maximum at higher altitudes, and therefore should lead to an altitude dependence in better agreement with experiment than the present computation.

[1] H. L. Kraybill, Phys. Rev. 73, 632 (1948).
[2] H. W. Lewis, J. R. Oppenheimer, and S. A. Wouthuysen, Phys. Rev. 73, 127 (1948).

B5. East-West Asymmetry of Cosmic Rays at 33,000 Feet.* W. C. BARBER, *University of California, Berkeley.*—By means of counter telescopes mounted in a B-29 plane, the east-west asymmetries of the total and hard components of the cosmic rays are being measured. The apparatus consists of six similar triple coincidence telescopes, three with 14 cm of lead and three with no lead. Preliminary measurements give the following results for a zenith angle of 45°.

$2\frac{(I_w-I_E)}{I_w+I_E}$	Probable error	Hard or total	Geomagnetic latitude	Altitude
0.11	±0.019	Total	~35°N	Average of 25,000 and 33,000 ft.
0.07	±0.034	Hard	~35°N	Average of 25,000 and 33,000 ft.
0.04	±0.015	Total	41°N	33,000 ft.
0.06	±0.034	Hard	41°N	33,000 ft.

The data indicate a predominance of positive primary particles for both the hard and total components. The soft component, which comprises about four-fifths of the total at these altitudes, must, therefore, also arise from primaries which are mostly positive. The statistical accuracy of the results for the hard component is poor, but since the hard is only a small fraction of the total intensity, errors here will not greatly affect the conclusion that the soft component has a positive east-west asymmetry.

* The research described in this abstract was supported in part by the Office of Naval Research.

B6. Energy Spectrum and Altitude Dependence of Slow Protons and Stars up to 30,000 Feet.* HARRIET H. FORSTER, *University of California, Berkeley.*—The nuclear emulsion technique has been used to obtain information on the energy distribution of low energy protons and stars at sea level and 30,000 feet. High altitude exposures were made on a series of B-29 flights at Inyokern, California. Between 30,000 feet and sea level, single proton trajectories with energies between 2.3 and 35 Mev decrease exponentially by a factor of $\exp(-P/1.3)$, where P is measured in meters of water equivalent. The exponential decrease of the star producing radiation is of the same order of magnitude. The integral energy spectrum of slow protons is found to be proportional to $\exp(-E/\epsilon)dE$, where ϵ is approximately 3 Mev. Calculations based on the above spectrum indicate that slow protons in the lower atmosphere can be accounted for by star production alone, as suggested by Bagge.[1]

* The research described in this abstract was supported in part by the Office of Naval Research.
[1] E. Bagge, Ann. d. Physik 521 (1941).

B7. Capture of Sea Level Negative Mesons by Nuclei. L. I. SCHIFF, *Stanford University.*—The rare appearance of ionizing radiation following the capture of a sea level (light or μ-type) negative meson by a nucleus suggests that "capture" consists of the conversion of μ^- into a neutral meson (μ^0), accompanied by the change of a nuclear proton into a neutron. The energy transferred to the nucleus would usually be small, and μ^0 would be easily detected only if it were to disintegrate into a pair of photons or charged particles. Capture will occur if heavy ($\pi^\pm$) mesons are strongly coupled to nucleons and can disintegrate into $\mu^\pm$ and μ^0; its probability is approximately proportional to Z^4. The intermediate step in the capture process then contains P, π^-, μ^0, or N, π^+, μ^-. The lifetime of $\pi^\pm$ for μ-decay can be related to the known rate of μ^- capture and the strength of nuclear forces. If $\pi^\pm$, $\mu^\pm$, and μ^0 are scalar mesons with masses 313 m, 200 m, and 100 m, respectively, this lifetime is about 4×10^{-8} sec., and the resulting $\mu^\pm$ has a few Mev energy. The lifetime of $\pi^\pm$ for β-decay, assuming that nucleons have no direct interaction with the electron-neutrino field, is significantly shorter than this, about 10^{-9} sec.

C1. Quantitative Relations for the Thresholds of Pre-Onset Positive, Burst Pulse Corona and of Positive Streamer Advance. LEONARD B. LOEB AND ROBERT A. WIJSMAN, *University of California, Berkeley.*—Loeb[1] has suggested that the form of threshold equations for onsets of self-sustaining discharges, including sparks by positive streamer mechanism, must bear a formal analogy to the Townsend low pressure criterion for a spark, e.g., $\gamma \exp\int \alpha dx = 1$. Here α is the first Townsend coefficient for ionization by collision and γ a coefficient representing the probability of electron emission by some secondary mechanism. With this approach it has been possible to derive expressions for the threshold of the pre-onset burst pulse corona from positive points, and for the threshold of streamer propagation and streamer conditioned spark breakdown, both processes involving photo-ionization of the gas near atmospheric pressure. Quantitative test is at present precluded as a result of ignorance of such quantities as photon production, photoelectric ionization probabilities, and absorption coefficients. The streamer equation replaces the Meek criterion for spark breakdown by streamer mechanism and supplies the deficiencies caused by omission of photo-ionization in that theory. These relations clearly indicate to the experimentalist the kind of data needed in order quantitatively to calculate various breakdown thresholds.

[1] L. B. Loeb, Rev. Mod. Phys. 20, 151 (1948).

C2. Effect of Point Material on Corona Onset.* W. N. ENGLISH, *University of California, Berkeley.*—Several observers have remarked on the near equality of the positive and negative intermittent corona onset potentials, V_g^+ and V_g^-, in a point-to-plane gap in air, as contrasted to values of V_g^- far below V_g^+ in pure hydrogen and nitrogen. In an article on the "Mechanisms of positive and negative coronas in air," submitted to the Journal of Applied Physics, L. B. Loeb concludes that the equality is fortuitous, and can be due only to an exceptionally high negative point work function in the presence of O_2. Accordingly, a study of the effect of a wide variety of point materials and conditions on corona onset seemed urgent. Roughly shaped points of CuO, FeS, and As have shown V_g^- considerably below V_g^+ at atmospheric pressure. Treatment of a Pt point by hydrogen ion bombardment in a glow discharge immediately before onset determination gave no significant change. A comparison of carefully formed 1-mm diameter points of C, Al, Zn, and Cu, and the effect of gradual oxidation and reduction of Cu points will be reported on.

* Work supported by the Office of Naval Research.

C3. Factors Affecting the Determination of Particles Size by the Hopper-Laby Stokes' Law Method.* WULF KUNKEL, *University of California, Berkeley. (Introduced by Leonard B. Loeb.)*—Most electrified particles observed by Hopper-Laby method in a study of dust electrification[1] appeared much larger than individual particle sizes present in the powders. Calculations on aggregation due to electrostatic attractive forces indicated that particle growth is negligible unless either the cloud density exceeds a million particles per cm^3 or the average charge of one sign exceeds 1000 electrons per particle. Deviations from Stokes' law by the particle shape might be considered responsible for such discrepancies. Experiments on the rate of fall of various models in a heavy oil showed that all shapes fall *more slowly* than the spheres of equal weight, thus appearing smaller than their true size in a Stokes' law estimate. The amount of particle surface seems the predominant parameter. The error in size estimate was rarely found to exceed fifty percent. Thus the dust particles observed were actually at least as large as estimated, and they must have existed as such before they started settling out.

* Work supported by the Office of Naval Research.
[1] Refer to J. W. Hansen, Phys. Rev. **73**, 532 (A) (1948).

C4. Point-to-Plane Impulse Corona.* D. B. MOORE AND W. N. ENGLISH, *University of California, Berkeley.*—A study of point-to-plane impulse corona in air at atmospheric pressure has been carried out, with a view to applying the impulse method to the determination of photo-ionization by positive corona streamers. Photographs of positive and negative corona from a 0.1-mm diameter point with two microsecond square pulses at potentials up to 12000 volts, show interesting peculiarities. With positive point burst pulse corona can be seen, and pre-onset streamers are particularly well developed, proceeding radially from the point, as a result of the absence of inhibiting space charge. Small groups of superimposed streamers are clearly seen, giving the corona a coarse streaked appearance. Attempts to photograph a single streamer have not yet succeeded. The negative point corona has a remarkable appearance. In addition to the normal brush-like structure associated with a steady negative potential, there is a concentrated central "streamer" spike and at higher impulse voltage, two side spikes. Tests have indicated no appreciable positive transient on the negative high voltage pulse. It is considered that the effect is due to a positive streamer discharge between the intense positive space charge near the point, left by an interrupted Trichel pulse, and the negative space charge further out in the gap.

* Work supported by the Office of Naval Research.

C5. Potential and Field Distribution in the Hemispherically Capped Cylindrical Point to Plane Corona Gap. JAMES M. PARKER AND LEONARD B. LOEB,* *University of California, Berkeley.*—Experience shows that hemispherically capped cylindrical point-to-plane electrode systems are the most satisfactory geometry for corona studies. Quantitative investigation of mechanisms requires that field distributions along the axis be known. As these are not amenable to computation, distribution was studied by large electrolytic model tank. Within limits of accuracy, a unique curve was observed for constant ratio of point radius r to gap length L. The ratio of gap length to plane radius R must be less than unity and large ratio L/r is desirable, thus setting a practical limit of 160. With this value the ratio of potential V at distance x from point surface to the applied potential V_0 was measured. Curves for V/V_0 as function (x/r) and $(dV/dx)(r/V_0)$ as function (x/r) have been determined which permit dV/dx to be evaluated as function of x for any radius. Applied to positive burst pulse onset corona threshold, $r=0.019$ cm in 760 mm air, the field at the point is exceedingly high, with very steep decline, throwing the ionization coefficients near the point into the Morton-Johnson[1] regime and making calculation of the Townsend integral difficult.

* Work supported by the Office of Naval Research.
[1] G. W. Johnson, Phys. Rev. **73**, 284 (1948).

C6. Point-to-Plane Corona Characteristics.* H. W. BANDEL AND W. N. ENGLISH, *University of California, Berkeley.*—A standard set of consistent corona data for point-to-plane geometry in air, covering variation in potential, point size and pressure, with current, oscilloscope, visual and photographic observations, has been urgently needed for the development of corona calculations and theory. These studies are being done in a brass chamber 30 cm in diameter by 30 cm with quartz windows. The ratio of the gap length to the radius of the platinum points has been kept constant at 160, as recommended by Loeb.[1] Positive and negative current-voltage curves with 0.5-mm diameter point in air at atmospheric pressure have been obtained from below 1000 volts to just under the sparking potential. Saturation currents caused by collection of externally caused ionization are observed below electron multiplication by collision and range around 10^{-13} ampere. A marked change in slope indicates the beginning of electron multiplication by collision near the point, and the curve is nearly linear up to intermittent onset, where the slope again becomes steeper and the current increases by a factor of 1000 in a few hundred volts. Above onset the corona currents are at first linear and then curve upward to the sparking potential as noted by previous observers.

* Work supported by the Office of Naval Research.
[1] See abstract C1 by Loeb and Parker.

D3. The Detection of Positive Mesons Produced by the 184-in. Cyclotron. A. S. Bishop, John Burfening,* Eugene Gardner, and C. M. G. Lattes, *University of California, Berkeley.*—Positive mesons have been produced by the 184-in. cyclotron and detected with photographic plates. The method of production is similar to that used for negative mesons.[1] Two methods of exposure to positive mesons are available: (1) Plates are placed below the circulating beam at a smaller radius than that of the target. Positive mesons emitted from the target with the proper energy in a forward direction are 180° focused upon the plates. (2) Plates are placed in the position initially used for exposure to negative mesons, but the shielding is modified to admit those positive mesons which are emitted from the target in the backward direction. Plates exposed in this way thus contain positive meson tracks which start at one edge and negative meson tracks which start at the opposite edge. In about half of the cases tracks of positive secondary mesons are observed to originate from the above-mentioned positive primary mesons. It is believed that all of the primary positive mesons decay into secondary mesons, but that in some cases the secondary meson is not seen because of unfavorable angle or bad background of neutron knock-ons, or both. This paper is based on work performed under Contract W-7405-eng-48 with the Atomic Energy Commission in connection with the Radiation Laboratory, University of California, Berkeley, California.

* Lieutenant Colonel, U. S. Army.
[1] Eugene Gardner and C. M. G. Lattes, Science **107**, 270 (1948).

D4. Meson Mass Estimation by Grain Counting in Photographic Emulsions. Walter H. Barkas,* Eugene Gardner, and C. M. G. Lattes, *University of California, Berkeley.*—Negative mesons produced by the 184-inch Berkeley cyclotron have been studied by means of Ilford C.2 photographic plates of emulsion thickness 50μ. The meson tracks lie approximately parallel to the plane of the emulsion, and often end in the emulsion. The track grains are about 0.35μ in diameter. For particles carrying one unit of charge, the number of grains, $N(R)$, in a residual range R is assumed to be given by $N(R)=Mf(R/M)$, where M is the mass of the particle. By counting grains in meson tracks and proton tracks found in the same plate, the mass ratio of meson to proton can be found. A consistent convention for estimating the number of grains which occur in clumps reduces subjective errors. Comparisons of masses obtained by grain counting and by magnetic deflection on the same particle are made. Results of different observers are also related. Masses of star producing and non-star producing mesons are compared. Assuming that just two types of mesons are represented, the observed values are 305 and 202 electron masses for the heavy and light mesons, respectively. This paper is based on work performed under contract with the Atomic Energy Commission in connection with the Radiation Laboratory, University of California, Berkeley, California.

* Office of Naval Research, San Francisco, California.

D5. The Detection of Light and Heavy Mesotrons outside the Tank of the 184-in. Cyclotron. Wolfgang K. H. Panofsky, *University of California, Berkeley.*—The mesotrons artificially produced by the 184-in. cyclotron* have been brought out of the cyclotron tank by means of a specially designed magnetic channel which brings mesotrons of $H\rho=148{,}000$ gauss$\pm$cm out of the field of 14,000 gauss at the target into a region of 4000 gauss in a re-entrant chamber in the cyclotron wall. Both light and heavy mesotrons have been detected in this chamber. A measurement of the lifetime of the heavy meson appears possible in this arrangement. The writer is indebted to L. W. Alvarez for suggesting the magnetic channel method. This work was sponsored by the Atomic Energy Commission.

* E. Gardner and C. M. G. Lattes, Science **107** (March 12, 1948).

D6. High Frequency Proton Source. R. N. Hall, *California Institute of Technology.*—An ion source and gun capable of producing beams of several hundred microamperes of 120-kev protons will be described. A 50-watt, 450-mc/sec. oscillator maintains an electrodeless discharge inside a barrel-shaped Pyrex discharge chamber of $\frac{1}{2}$-cc volume. An axial magnetic field of 1000 gauss greatly improves the performance. The r-f voltage is applied between the ends of the discharge chamber which contain holes through which the hydrogen and ions pass. The ions which diffuse out through the 0.040-in. diameter exit hole are accelerated without the use of a probe. A differential pumping arrangement removes most of the hydrogen which would otherwise enter the accelerating column. Typical operating conditions are: gas flow, 35 cc/hr. (N.T.P.); total beam current collected by 2-in. aperture, 420 μa; mass one (proton) current collected by $\frac{5}{8}$-in. aperture, 210 μa; mass two current, 115 μa; mass three current, 40 μa; ratio of mass one protons to hydrogen molecules consumed, 0.005; current density at the exit hole due to mass one protons, 0.027 amp./cm^2. The source operates well at reduced rates of gas flow with the ratio of mass one protons to hydrogen molecules increasing to 0.01. This work was assisted by the Office of Naval Research.

D7. Low Energy $C^{12}(p,\gamma)$ Cross Section. W. A. Fowler and R. N. Hall, *California Institute of Technology.*—The low voltage accelerator and high frequency ion source described in the previous abstract have been used to measure the cross section of the reaction $C^{12}(p\gamma,\beta^+)C^{13}$ in the 100- to 120-kev energy range. Preliminary results indicate that at 100 kev the thick target yield is 7×10^{-17} positrons per proton corresponding to a cross section of approximately 10^{-34} cm^2. A special thin-walled bell jar beta-ray counter obtained from the Radiation Counter Laboratories with a sensitive volume 1.2 cm in length and 2.8 cm in diameter was employed to measure this low yield. A belt of ten conventional counters in anticoincidence was used to reduce the background counting rate under $4\frac{1}{2}''$ of lead from 10 counts/min. to 6 counts/min. The cross section calculated using the dispersion formula, including barrier penetration factor from the characteristics of the 453 kev resonance ($\Gamma_p=35$ kev, $\Gamma_\gamma=0.63$ ev),[1] is 0.4×10^{-34}

cm^2. The theoretical expression used by Bethe[2] in the absence of experimental data in calculating cross sections at stellar temperatures gives a cross section at 100 kev of 1.2×10^{-36} cm^2. The results at 100 kev and at resonance indicate that the stellar cross section may be 100 times as great as that employed by Bethe. This work was assisted by the Office of Naval Research.

[1] Fowler, Lauritsen, and Lauritsen, Rev. Mod. Phys. **20**, 275 (1948).
[2] H. A. Bethe, Phys. Rev. **55**, 434 (1939).

D8. Energy Production in the Sun. J. O'REILLY AND R. F. CHRISTY, *California Institute of Technology.*—The experiments described in the previous abstract show that the cross section for the reaction $C^{12}(p, \gamma)N^{13}$ for protons of about 100-kev energy is approximately 100 times larger than that used[1] in calculating the energy production of stars. Under the assumption that the carbon cycle is responsible for the energy production of the sun, this implies that the central temperature of the sun must be much smaller than assumed heretofore. Preliminary calculations indicate a value of about 15×10^{6}°C. This low temperature, combined with the stability and luminosity equations, implies a mean molecular weight in the neighborhood of 0.6 and a heavy element concentration (Russel mixture, for example) of only about 1 percent by weight. The ratio of hydrogen to helium, which together account for about 99 percent of the mass, is thus fairly large but not as yet well determined. Detailed calculation of these questions is being carried through. This work was supported in part by the Office of Naval Research.

[1] H. A. Bethe, Ap. J. **92**, 118 (1940).

E4. Radioactive Potassium. R. V. LANGMUIR, *General Electric Company.*—During a search for short lived nuclear isomers with the 70 Mev synchrotron a new activity was observed in the bombardment of several potassium salts. The observed half-life was 1.3 ($\pm$0.1) seconds. It is suggested that this is one of the mirror nuclei,[1] and that the reaction is $K^{39}(\gamma, 2n)K^{37}$. A calculation of $tF(e_0)$ shows this interpretation to be possible. No short lived isomers with half-lives between 100 microseconds and 1 second were observed in the 55 elements bombarded. This work has been supported by the Office of Naval Research.

[1] E. Konopinski, Rev. Mod. Phys. **15**, 209 (1943).

E5. The Half-Lives of Aluminum^{25} and Aluminum^{26}. HUGH BRADNER AND J. D. GOW, *University of California.*—The availability of separated isotopes of Mg makes it easy to determine the half-life of Al^{25}, a member of the Wigner series which has long been suspected to have a half-life of approximately 7 seconds, but which has not been confirmed because of the masking 7-second activity of Al^{26}. Mg^{24}, Mg^{25}, and Mg^{26} (in the form of MgO) have been bombarded with protons from the Berkeley linear accelerator, with the following results: Mg^{24} yields an activity of approximately 20 seconds half-life, presumably due to Na^{21} from the reaction $Mg^{24}(p, \alpha)Na^{21}$. The Mg^{25} yields an activity of 7.3-seconds half-life, which we assign to the reaction $Mg^{25}(p, n)Al^{25}$. The Mg^{26} yields an activity of 6.3-second half-life, assigned to Al^{26} according to a similar reaction. It seems probable, therefore, that the 7-second half-life normally given for Al^{26} is a mixture of these two activities. This paper is based on work performed under contract with the Atomic Energy Commission in connection with the Radiation Laboratory, University of California, Berkeley, California.

E6. Assignment of 48-Min. and 2-Min. Isomers of Cd. A. C. HELMHOLZ AND C. L. MCGINNIS, *University of California, Berkeley.*—The assignment of the 48-minute isomerism to Cd^{111} by Goldhaber[1] has been verified by bombardment of enriched isotopes with fast neutrons. The activity has also been produced by high energy alphas (>20 Mev) on Ag ($Ag(\alpha, pn)$), and Pd^{108} (α, n). Attempts to separate this activity from the 2.7-d In^{111} have failed, showing that the γ-ray of energy 173 kev observed in its decay[2] is not the same as that of energy 145 kev reported in the 48-min. isomerism by Hole.[3] Further work on these γ-rays will be reported. The 2-minute isomerism in Cd has been assigned to Cd^{113} also by bombardment of separated isotopes with fast neutrons. Initial measurements have given 2.3 min. as the half-life. This paper is based on work performed under contract with the Atomic Energy Commission in connection with the Radiation Laboratory, University of California, Berkeley, California.

[1] Abstracts of Washington Meeting.
[2] J. L. Lawson and J. M. Cork, Phys. Rev. **57**, 982 (1940).
[3] Hole, N. Ark. Mat. Ast. Fys. **345**, No. 19 (1947).

E7. Radioactive Products of High Energy Deuteron Bombardment of Cu. DOROTHY BOCKHOP, A. C. HELMHOLZ, AND J. M. PETERSON, *University of California, Berkeley.*—Serber[1] has suggested inelastic collisions in which only a fraction of the available energy is lost as the initial step in the formation of nuclei by high energy particle bombardment. The nucleus thus excited subsequently boils off particles and energy. This theory differs from that of the compound nucleus, which holds at low energies, in that the incident particle is not captured. Serber's theory has been applied with success to several cases.[2] The characteristic feature of the excitation function is the large value of cross section at high energies (~5 times the threshold) relative to that predicted by the theory of the compound nucleus. The formation of atomic number $Z+1$ from target of atomic number Z cannot proceed by this process since it requires the capture of a proton, although another possibility would be an exchange collision between incident proton and a neutron. The excitation functions of a number of radioactive species from the bombardment of Cu with 190-Mev deuterons have been measured. Chemical separation of a number of fractions, including Zn, Cu, Co, and Ni, were performed. The Zn^{63} and Zn^{62} activities which must be formed as mentioned above show maxima at less than 50 Mev, and steady decreases to the highest energy measured (140 Mev) where the values are less than $\frac{1}{3}$ those of the maxima. This is in accord with considerations of the compound nucleus. However, Ni and Co activities show maxima at low energies, minima and subsequent increases at higher energies, such as are characteristic of Serber's theory. This work is based on work performed under contract with the Atomic Energy Commission in connection with the Radiation Laboratory, University of California, Berkeley, California.

[1] R. Serber, Phys. Rev. 72, 1114 (1947).
[2] R. L. Thornton and R. W. Senseman, Phys. Rev. 72, 872 (1947); W. W. Chupp and E. M. McMillan, Phys. Rev. 72, 873 (1947).

E8. Excitation Curves of $C^{12}(p, pn)C^{11}$ and $B^{11}(p, n)C^{11}$ up to 32 Mev. ROBERT PHILLIPS AND WOLFGANG K. H. PANOFSKY, *University of California, Berkeley.*—The excitation curves of $C^{12}(p, pn)C^{11}$ and $B^{11}(p, n)C^{11}$ have been obtained by the stacked foil technique using accurately molded boron carbide and polystyrene sheets. 32-Mev protons from the linear accelerator were used as the bombarding particle. Because of the homogeneity of the linear accelerator beam, very accurate resolution near the threshhold has been obtained. The shape of the curve will be discussed. This work was sponsored by the Atomic Energy Commission.

F1. The Ratio (e/m_0) for Free Electrons by Use of a Resonant Cavity. CHARLES H. WILTS, *California Institute of Technology.*—A deflection method for measuring (e/m_0) for free electrons is described. A beam of electrons is directed along the axis of a cylindrical cavity excited in the TM_{110} mode. A null in the subsequent deflection of the beam occurs when the transit time is nearly equal to an integral number of cycles of the cavity oscillation. Three quantities must be measured: a distance, a frequency, and a difference of potential; two very small corrections must be made. An accuracy of 1 part in 10,000 seems to be achievable Preliminary apparatus gave a value: $e/m_0=1.759\pm.007(10)^7$ e.m.u. per gram.

F2. Wave-Guide Fast Counter. R. F. POST, *Stanford University.*—The theory is given for a fast counter which would operate by measuring the change in phase velocity of propagation in a gas-filled wave guide induced by primary ionization from a high energy charged particle. It is shown that increased sensitivity can be achieved by applying a longitudinal magnetic field sufficient to make the Larmor frequency of the electrons equal to the applied radiofrequency. This effect is similar to the critical phenomena associated with the propagation of radio waves in the ionosphere. Such a counter should have short response and resolving time, but this can only be obtained at the expense of sensitivity and solid angle. Thus the device will probably be useful only for the counting of heavily ionizing particles for which the path direction is accurately known. Possible methods for increasing counter sensitivity are discussed.

F3. Method of Measuring Cavity Impedance.* W. W. HANSEN AND R. F. POST, *Stanford University.*—In the design of a linear electron accelerator it has become necessary to measure the normalized value of the line integral of electric field along the axis of an accelerator cavity. An experimental method has been developed which gives results accurate to 3 or 4 percent. The method consists of measuring the shift of resonant frequency produced by perturbing the wall of the cavity on the axis at one end by means of a movable cylindrical plunger, and of taking the slope of the frequency *vs.* plunger height curve at the point where the plunger is flush with the cavity wall, for which case the perturbation theory surely applies. From this measurement the normalized value of E at one point on the axis is obtained, and a separate simple experiment yields the variation of E along the axis. This enables one to compute the value of the desired integral. The method has been checked by applying it to simple cylindrical cavities for which the integral may be evaluated analytically. In these cases it gave results accurate to less than 2 percent.

* This work was supported by Office of Naval Research.

F4. Continuous Spectrum of X-Rays to 13A.* S. T. STEPHENSON AND F. D. MASON, *Washington State College.*—Previous work on the continuous spectrum of x-rays ends at 2.8A as an upper limit for wave-length and 7 kv as the lower limit for voltage. The present paper describes results obtained up to 13A in wave-length and down to 1.2 kv. A vacuum Geiger counter x-ray spectrometer[1] was used with a mica crystal. A counter of special window design to allow for either excess pressure from without or, after evacuation of the spectrograph, from within was used with windows of Al as thin as 0.0003 inch. Corrections are made for background, the absorption of tube windows, counter efficiency, and for the reflecting power of mica (although this latter correction is an extrapolated correction gotten by comparing mica with calcite out to 4.5A). The intensity of radiation appears to depend, as at the shorter wave-lengths, on the first power of the atomic number and the square of the voltage. The shape of the curve, however, quite definitely changes at long wave-lengths. The maximum in the curve of intensity against wave-length comes closer to the short wave cut-off than at shorter wave-lengths, and the general pattern approaches the one to be expected from a thin target.

* Assisted by the Office of Naval Research.
[1] S. T. Stephenson and F. D. Mason, Phys. Rev. 72, 744 (1947).

F5. Properties of Cerenkov Radiation Near the Threshold. JOHN M. HARDING AND JOSEPH E. HENDERSON, *University of Washington.*—A study has been made of Cerenkov radiation from mica in the vicinity of the threshold predicted classically when the incident electron travels with a velocity equal to the velocity of the light which it produces in the medium. The electrons were directly accelerated by means of a Van de Graaff generator and passed through a transverse magnetic field. The magnetic field served not only to provide velocity selection and focusing, but also eliminated the direct light from the filament of the tube from confusing the interpretation of the light from the mica. It is found that: (1) A threshold does exist very close to the conditions predicted by simple theory. (2) The light at the threshold is unpolarized and rapidly becomes polarized as the electron energy exceeds the threshold and the cone of radiation expands. (3) The total radiation increases approximately linearly with energy above the threshold energy over the region investigated, which is about twice the threshold. This information at the larger values of electron energy becomes increasingly uncertain due to larger angles of emission, introducing internal reflection problems within the mica.

G3. Precision Spectroscopy of Nuclear Gamma-Rays with a Focusing Curved Quartz Crystal.* JESSE W. M. DUMOND, DAVID LIND, AND BERNARD B. WATSON, *California Institute of Technology.*—A newly developed precision instrument and technique is described which has permitted the extension of the methods of the focusing curved crystal x-ray spectrometer into the nuclear gamma-ray region. The range of the instrument, 500 x.u. to 8 x.u. or less, permits *establishment of a precision link between the well established scale of x-ray wave-lengths and the wave-lengths of nuclear gamma-rays*. The wave-length of the 0.41-Mev gamma-ray line from Au^{198} has been measured with a precision better than two parts in 10000. The chief limitation comes from the weak crystal reflection at short wave-lengths (see a companion abstract in this program). The proposed program includes the establishment with strong neutron activated sources of a number of precisely defined gamma-ray wave-lengths to serve as easily reproducible *fixed points* in this region of the spectrum. Since these gamma-ray lines can in turn be used to eject photoelectrons in β-ray spectrometers, the precision thus made available can be used in the calibration of β-ray spectra to increase the precision of our knowledge there also. Therefore, it is hoped that this technique of direct spectroscopy of gamma-rays ushers in a new era of precision in nuclear energy measurements.

* Assisted by the Office of Naval Research.

G4. The Reflecting Power of the (310) Planes of a Curved Quartz Crystal for X-Rays and Gamma-Rays from 494 x.u. (Sn $K\alpha$ X-Rays) to 30 x.u. (Au^{198} Gamma-Rays). Experimental Results and Theoretical Interpretation.* DAVID LIND, BERNARD B. WATSON, AND JESSE W. M. DUMOND, *California Institute of Technology.*—Using the 2-meter focusing curved quarts crystal spectrometer[1] with (1) concentrated sources of nuclear gamma-rays and (2) secondary fluorescent sources of x-rays placed at the focus we have measured, as a function of λ, by means of a multicellular gamma-ray counter,[1] the ratio Γ of counts reflected to counts of wave-length λ incident on the (310) planes of the quartz crystal. Γ, to some extent an instrumental constant, depends on the overlapping of four distribution functions: (1) The pattern produced by the geometrical aberrations of focus. (2) The distribution of source intensity. (3) The diffraction pattern curve of the (310) planes of the quartz crystal at the wave-length used. (4) The "natural line profile" of the radiation, λ. At 500 x.u. Γ, in our instrument, is nearly 18 percent while at 30 x.u. it has fallen to 0.3 percent. The "integrated reflection coefficient" R (the integral of curve (3) above) has been calculated from our measurements of Γ. R we find is quite closely proportional to the square of the wave-length. This is explicable if one assumes that the curved quartz lamina behaves in this spectral range like a mosaic of domains small compared to the primary extinction length.

* Supported by the Office of Naval Research.
[1] See companion abstract in this programme; also Rev. Sci. Inst. 18, 626 (1947).

G5. A Method of Studying the Gamma-Ray Spectrum of the Annihilation Radiation from a Source of Positrons Using the Focusing Curved Crystal Spectrometer.* BERNARD B. WATSON, DAVID A. LIND, AND JESSE W. M. DUMOND, *California Institute of Technology.*—Behind a deep jawed lead slit placed at the focus of the gamma-ray spectrometer[1] there is placed a strong source of positrons of considerably greater dimensions than the slit. The spectrum of the annihilation radiation coming from the recombination of the positrons with negative electrons in that region of the source material which is directly behind the slit is then studied with the spectrometer both for spectral distribution and precision wave-length determinations.

* Assisted by the Office of Naval Research.
[1] This instrument is described in a companion abstract on this programme. See also Rev. Sci. Inst. 18, 626 (1947).

H1. Counting Efficiency of Scintillation Counter. A. V. TOLLESTRUP, *California Institute of Technology.*—Efficiency curves for a scintillation type counter for low energy protons, deuterons, and alpha-particles will be presented. The counter consists of a 931A multiplier tube, and a zinc sulfide phosphor obtained from the Radio Corporation of America.[1] A conventional amplifier which has a gain of 500 is used. The counter can be sealed directly onto the vacuum system of the accelerators used in the study of nuclear reactions. Thus the problems associated with thin windows are eliminated. Protons of energy as low as 17 kev have been counted. The background due to dark current in this case was 300 counts per minute. Protons whose energy is 80 kev give pulses large enough to allow complete discrimination against the dark current pulses. This work was assisted by the Office of Naval Research.

[1] J. W. Coltman and Fitz-Hugh Marshall, Nucleonics 1, No. 3 (November 1947).

H2. Design and Performance of a 15-cm Electrostatic Analyzer. SAMUEL K. ALLISON AND HAROLD V. ARGO, *University of Chicago.*—An electrostatic deflector for high energy ions, intended for use with an electron multiplier tube, has been designed, constructed, and is in operation. The ions are deflected through 90° between two cylindrical plates 5 millimeters apart with average radius of 15 cm. Both plates are mounted on a heavy quartz post at the axis of the instrument and each plate can be charged to high voltage independently. Tolerance on the diameter of the quartz post has been held to ± 0.0001 inch and on the radii of the plates to ± 0.001 cm. Slits of adjustable width are incorporated in the design and can be moved from outside the vacuum wall transversely to the ion beam and parallel to it, thus allowing the experimental location of conjugate foci. It is computed that the fraction of the particles focused from a monoenergetic source emitting in all directions is 1.7×10^{-4}. At the present time singly charged ions up to 600-kv energy have been deflected and detected with negligible background in the multiplier tube by charging one of the plates to 40 kv, and indications are that the upper energy limit of the instrument is still higher than this. The resolution is a function of the slit width which can be readily adjusted without breaking the vacuum, and the instrument has been operated at a resolving power of 0.3 percent in energy.

H3. An Improved Lock-In Amplifier. WALTER C. MICHELS AND ESTHER D. REDDING, *Bryn Mawr College.*—The design of the lock-in amplifier previously used in this laboratory[1] has been modified to produce a semiportable instrument of increased sensitivity and selectivity. One stage of pentode amplification has been added, the stability has been improved, and the phase shifter has been transferred from the input to the lock-in circuit. With these changes and with a 19.5-ohm type H.S. galvanometer as the final detector, sensitivities up to 2.5×10^{5} mm/volt have been obtained at 800 cycles. The amplifier operates successfully with an inductive input of 2×10^{6} ohms impedance at this frequency so that the maximum current sensitivity is of the order of 10^{12} mm/ampere. The selectivity has also been improved, largely because the increased stability has allowed the use of a longer period (7 sec.), more sensitive galvanometer. The measured response is fifty percent of the maximum at 0.1-cycle/sec. deviation from the lock-in frequency and drops to one percent if the frequency departs by 0.6 cycle/sec.

[1] Walter C. Michels and Norma L. Curtis, Rev. Sci. Inst. **12**, 444 (1941).

H4. Reaction Time of Parallel-Plate Counters. J. W. KEUFFEL, *California Institute of Technology.*—The uncertainty in the reaction time of the parallel-plate counters described previously[1] is being studied. The uncertainty is measured by placing one counter directly above another and observing by means of a 10-detector chronotron[2] the distribution of time lags of one counter relative to the other. Preliminary results show that half the relative lags fall within $\pm12\times10^{-9}$ sec. at an overvoltage of 500; at an overvoltage of 1000 the uncertainty is $\pm4\times10^{-9}$ sec. By varying the voltage on one counter some idea as to the absolute value of the lags may be obtained. Such tests indicate that better parallelism may improve the precision attainable, as the present lags could be due to variations in field strength from point to point. The lifetime of the counters at 1000 volts overvoltage seems to be about a month of background rate counting.

[1] J. W. Keuffel, Phys. Rev. **73**, 531 (1948).
[2] Neddermeyer, Althaus, Allison, and Schatz, Rev. Sci. Inst. **18**, 488 (1947).

H5. On Diffraction under Small Angles by Three-Dimensional Lattices. OTTO HALPERN AND EDWARD GERJUOY, *University of Southern California.*—We have continued the investigation[1] of small angle diffraction by crystals, taking into account lattice errors and interference between perfect crystal blocks. Results of a rather general nature have been obtained under diverse assumptions about the structure of the crystal or polycrystal. We find, e.g., for a representative case that the integral cross section σ_e of scattering into angles lying between the zero'th and first Laue spot (Debye ring) is given by $\sigma_e=C\sigma_0N(\lambda/\pi a)^2$. Here σ_0 is the atomic differential cross section for forward scattering multiplied by 4π, a the lattice distance, λ wavelength, N number of atoms in scatterer, C a numerical constant of order $\frac{1}{2}$. Various applications to the scattering of light ($\lambda\gg a$) as well as to that of neutrons ($\lambda\sim a$) and hard radiations ($\lambda\ll a$) will be discussed.

[1] Otto Halpern, Phys. Rev. **73**, 653 (1948).

H6. The Average Negative Gradient of Potential Energy. F. W. WARBURTON, *University of Redlands.*—Methods of developing the Lagrangian equations are applied to the variation in potential energy V of two bodies to verify the general equation,

$$\cdots-(d^2/dt^2)(\partial V/\partial\ddot{q})+(d/dt)(\partial V/\partial\dot{q})-(\partial V/\partial q)=F_q.$$

Use is made of the integral $\int(F_q\delta q)dt$ divided by the time interval t_2-t_1, as expressing the average work done by the variable force F_q exerted by one body on the other. As the forces concerned are functions of relative velocity which are not bound by the classical Lorentz force, the contention that "magnetic forces do no work" does not affect the validity of this extended concept of potential energy. An advantage of replacing the Lagrangian function $L=T-V$ by V and the kinetic energy T separately, is that F_q may be determined from V alone or may be expressed in terms of T alone, when one considers the mechanical energy gained by the electron as the result of *all* the external forces.

H7. Modes of Vibration in Contoured Quartz Plates.* RENATE S. BEVER, VIRGIL E. BOTTOM, AND LOUIS R. WEBER, *Colorado A. & M. College.*—The admittance spectrum of flat quartz plates vibrating in thickness shear shows numerous inharmonic overtones having frequencies within a few percent of the fundamental frequency. These overtones seem to be spaced at random; many are coupled together. Making the major surfaces of the plate convex causes dispersion of the overtone modes and decreases the coupling between them. Chladni patterns of such contoured plates show the vibrations to be restricted to a small area and independent of the remaining peripheral portion; the frequencies are determined by the thickness of the outermost loop of the individual patterns. Moreover, these inharmonic overtones may be grouped into series associated with standing waves along X, Z', or one of the "diagonal" directions, since the difference between the frequencies of the modes of each series is very nearly constant and depends upon the curvature of the surfaces and the elastic modulus in the direction of the standing wave train. Thus the overtone spectrum of a contoured quartz plate vibrating in thickness shear may be resolved into a set of series having a definite regularity.

* This work supported by Signal Corps Contract.

H8. High Frequency Loading. NICHOLAS BEGOVICH, *California Institute of Technology.*—An interesting high frequency loading phenomena occurring in very closed spaced vacuum tubes has been reported.[1] The experimental set-up is the measurement of the shunt conductance at 3.0×10^9 c.p.s. of a diode as a function of the retarding voltage on the anode. With large values of retarding voltage the impedance is the same whether the cathode is operating or turned off. With the cathode operating and decreasing the retarding voltage, the conductance sharply increases and reaches a maximum value before any electrons are collected at the anode. A calculation of the to and fro electron transit time, taking into account the Maxwellian velocity distribution, indicates that

$$G \leqq 3.44\times10^{-4} I_e T V_a^{-2} h^{-1} \times\{(h+2)\exp(-1/h)\,{}_1F_1(1/2;\,3/2;\,1/h)-h\}\ \text{mhos/cm}^2,$$

where I_e is the emission current density, T the absolute temperature of the cathode, ${}_1F_1(1/2;\,3/2;\,1/h)$ the confluent hypergeometric function, V_a the anode retarding voltage, d the diode spacing in cm, ω the angular frequency, and $h=1.021\times10^{19} V_a^2 T^{-1}(\omega d)^{-2}$.

[1] Hamilton *et al.*, *Klystrons and Microwave Triodes* (McGraw-Hill Book Company, Inc., New York), p. 156.

H9. On the Theory of a New Magneto-Electric Effect. ELLIOT T. BENEDIKT, *North American Aviation, Inc., Los Angeles.*—It is the purpose of the present paper to show the possibility of producing electrostatic effects by means of unhomogeneous magnetic fields. Consider a system of particles having a magnetic moment and subjected to an unhomogeneous magnetic field. The particles will be subjected to a force which will alter their space distribution. If the particles have, furthermore, an electric charge, this space distribution will, in general, produce an electric field. Such an effect can be expected with ferromagnetic colloidal particles, ions, electrons in a metal, and particles (nuclei, electrons) belonging to atoms or molecules. In the latter case, an electric polarization of the atoms or molecules should be obtained for magnetic fields strong enough to remove the coupling between the magnetic moments of the various constituents of the particle. It is interesting to notice the different results which can be expected according to whether the laws of classical or quantum electrodynamics are assumed to be valid. In the former case, the particles will be in stable rotational equilibrium if their magnetic moment is parallel to the field; consequently, all the particles will be forced to move toward the region of greatest field intensity. In the latter case, a number of stable orientations or the moment of the particles is possible, and therefore some of them will be forced to move toward the region of greatest field intensity, and some in the opposite direction. The electron density will therefore have a minimum inside the metal. The detailed theory of the effect for an ionized medium and an electron gas will be given from the classical and quantum-mechanical point of view, respectively.

H10. The Quantization of Unitary Field Theories. R. J. FINKELSTEIN, *Institute for Advanced Study.*—In a unitary field theory particles appear not as singularities but as small volumes of the field in which charge and energy are concentrated. In a theory of this nature, which is necessarily non-linear, all particle properties, such as their equations of motion, follow from the field equations. We have studied the quantization of such a theory without specializing the Lagrangian. Momentum (G_α) and angular momentum ($M_{\alpha\beta}$) of particles appear naturally and a relativistic definition of the position (X_α) of a particle may be given in terms of $M_{\alpha\beta}$ and G_α. The commutators of these particle observables (X_α, G_α, $M_{\alpha\beta}$) agree with current theory if the fields are quantized according to the usual (Einstein-Bose or Fermi-Dirac) rules. (The Born-Infeld theory did not meet this requirement because it was not strictly unitary.) The connection between velocity and momentum and the equation of motion of particles which follow from the field equations are the usual ones. Operators for mass, charge, and spin may be defined; these mutually commute and permit the usual classification of the elementary particles according to charge, mass, and spin. Mass and position are not simultaneously observable, even if knowledge of momentum is given up. External fields cannot be measured with arbitrary accuracy at the position of a particle. Magnetic moment and charge, on the other hand, commute with external fields. The non-linearity present in the usual field theories is sufficient to permit the existence of particle-like solutions under certain conditions. Hence we may derive from the current field theories a class of non-trivial unitary theories by postulating that only those solutions of the current theory which are free from singularities are physically admissible.

H11. Behavior of Spherically Tipped Bodies in the Early Stage of Water Entry. HAROLD WAYLAND AND SAUL BAKER, *Naval Ordnance Test Station, Pasadena.*—The behavior of large spherically tipped bodies projected obliquely into water is examined both theoretically and experimentally, particularly during the stage in which the body is balanced on its nose in the cavity. The theory is based on the assumption that the only hydrodynamic force acting on the body in the cavity can be represented by a force acting through the center of the spherical tip in the direction of motion of the c.g. of the body, and that the force is proportional to the square of the velocity of the body. The agreement between theory and experiment confirms the validity of these assumptions within practical limits. Equipment for precise measurement and recording of angular positions is described which is capable of withstanding the shocks occurring at water entry and recording throughout the entry phase.

H12. A Family of Rotational Corner Flows. R. C. PRIM, *Naval Ordnance Laboratory, White Oak, Maryland.*—A formally simple family of truly rotational solutions for the equations governing steady plane flow of an ideal gas in the absence of body forces is discovered. This family of solutions is rotational with respect to both the reduced velocity field and the actual velocity field. These rotational flows are related to the irrotational Prandtl-Meyer corner flow, which is included in the family as a special case. The equations of the streamlines and isobars and equations for the distribution of velocity components, pressure, density, and Mach number are given. General properties of the flows are discussed and examples of flow patterns exhibited.

I1. A Non-Homogeneous Cosmological Model with a Finite Cosmological Constant. GUY C. OMER, JR., *California Institute of Technology.*—The cosmological models described earlier[1] have been generalized to include a finite cosmological constant. In the neighborhood of the assumed observer in the model we take the average density as 10^{-29} g/cc at the present time, the cosmological constant as 8.78×10^{-19} (lt. yr.)$^{-2}$, and the radius of curvature as 10^{10} lt. yr. Then we find the total time elapsed in this neighborhood since the beginning of the expansion to be 3.64×10^{9} yr. This is in agreement with the probable range of astronomical time given by Bok[2] and with the estimated age of the earth stated by Holmes.[3] The calculated red shifts, except for the two Ursa Major clusters, agree with the observed red shifts given by Hubble[4] to within 0.1 magnitude. The calculated values of $\log N$, the nebular counts, depart from the observed values presented by Hubble[4] by 0.002 or less.

[1] G. C. Omer, Jr., Phys. Rev. **72**, 744(A) (1947).
[2] B. J. Bok, M.N.R.A.S. **106**, 61 (1946).
[3] A. Holmes, Nature **159**, 127 (1946).
[4] E. Hubble, Astrophys. J. **84**, 517 (1936).

I2. Existence of Tensor Interactions between Nucleons. ROY THOMAS,* *St. Louis University.*—Various meson theories predict exchange and tensor nuclear interactions. The angular dependences of the neutron-deuteron and the proton-deuteron cross sections for elastic collisions are calculated. The interaction between nucleons is assumed to be:

$$V(r_{ij})=G_{ij}[1+\alpha S_{ij}]J(r_{ij}).$$

S_{ij} is the tensor operator and G_{ij} represents the exchange nature of the interaction. α and $J(r_{ij})$ are adjusted to give the binding energy and a four percent D state to the deuteron, and G_{ij} is normalized to unity for the deuteron. Calculations show that for relative energies to 10 Mev only S and P waves contribute to the scattering. the tensor terms contributing little. For much higher relative energies the D wave contributes and in this case the tensor terms dominate the scattering. The angular dependence of the scattering produced by the tensor terms shows a significant difference from the non-tensor terms.

* Now at Oregon State College.

I3. A Double-Focusing Magnetic Spectrograph. C. W. SNYDER, C. C. LAURITSEN, W. A. FOWLER, AND S. RUBIN *California Institute of Technology.*—A magnetic spectrograph for analyzing charged particles emitted in nuclear reactions has been built, adapted from the design of Svartholm and Siegbahn[1] for electrons. Particles are deflected through 180° between steel pole pieces shaped to give a field decreasing radially approximately as $r^{-\frac{1}{2}}$ so that two-directional focusing is obtained. The central path has a radius of 28 cm, and the maximum field is 7600 gauss with a 4.5-cm gap. Protons of 2 Mev can be analyzed. With the present field shape, there is some astigmatism when source and image are placed symmetrically, but it can be minimized so that a nearly point focus is obtained by moving the source farther away from the end of the pole pieces. The field is measured by a torsion-type magnetometer calibrated by elastic scattering at known bombarding voltages. The effective angle, relative to the bombarding beam, of the particles entering the spectrograph is also determined by elastic scattering, and the consistency of results with various bombarding energies and targets indicates a precision of approximately 0.1 percent in measuring momenta. This work was supported in part by the Office of Naval Research.

[1] Svartholm and Siegbahn, Arkiv f. Astro., Mat., Fys. **33A**, No. 21 (1946).

I4. Inelastic Scattering of Protons from Li^7. S. RUBIN, C. W. SNYDER, C. C. LAURITSEN, AND W. A. FOWLER, *California Institute of Technology.*—The energy of the lowest excited state of Li^7 has been measured with the double-focusing magnetic spectrograph by measuring the energy of the group of inelastically scattered protons from a thin lithium target bombarded by 1222-kev protons. The spectrograph was calibrated by elastic scattering of 1222-kev protons from gold, beryllium, carbon, and oxygen. The bombarding proton energy is fixed to better than 1 kev by an electrostatic analyzer,[1] calibrated at 440 kev with the γ-ray resonance from $Li^7(p, \gamma)$.[2] The chief sources of error are in the shape of the peak obtained with the inelastically scattered protons, and in the calibration of the electrostatic analyzer. Both amount to 0.3 percent in terms of energy. The result of this determination is 480 ±2 kev, in good agreement with the measurement of Hornyak and Lauritsen on the γ-ray accompanying the decay to the ground state, discussed in an accompanying abstract. These two results can be combined to locate the resonance in $Li^7(p, \gamma)$ conventionally taken at 440 kev on the nuclear energy scale[3] at 439 ± 3 kev with respect to annihilation radiation at 510.8 kev. This work was assisted by the Office of Naval Research.

[1] W. A. Fowler, C. C. Lauritsen, and T. Lauritsen, Rev. Sci. Inst. **18** 818 (1947).
[2] W. A. Fowler, C. C. Lauritsen, and T. Lauritsen, Rev. Mod. Phys. **20**, 236 (1948).
[3] L. R. Hafstad, N. P. Heydenburg, and M. A. Tuve, Phys. Rev. **50**, 504 (1936).

I5. Short-Range Repulsion as a Mechanism for Nuclear Saturation. G. PARZEN AND L. I. SCHIFF, *Stanford University.*—Nuclear saturation can be explained by a short range repulsion and a longer range attraction between each pair of nucleons.[1] An attempt has been made to fit the density of heavy nuclei, deuteron binding energy, ortho-para and crystal scattering data, proton-proton scattering, and neutron-proton scattering at 90 Mev, by means of a square potential of this type. For parameters that give the correct deuteron energy, the magnitude of the scattered triplet amplitude at zero energy is greater than for a square well of the same over-all range; thus the range is so small that the density of heavy nuclei is excessive. Introduction of the repulsion worsens the agreement of the square well potential with the proton-proton scattering below 1 Mev. At 90 Mev, the new potential tends to make the phase shift δ_1 larger than δ_0 and δ_2, but the effect is not pronounced enough to give the observed backward maximum in the neutron-proton scattering. It is concluded that a short-range repulsion is not an adequate substitute for an exchange interaction.

[1] H. A. Bethe and R. F. Bacher, Rev. Mod. Phys. 8, 161 (1936); H. A. Bethe, *Elementary Nuclear Theory* (John Wiley & Sons, Inc., New York, 1947), p. 81; see also P. M. Morse, J. B. Fisk, and L. I. Schiff, Phys. Rev. 50, 748 (1936).

I6. On Neutron-Proton Scattering Models. L. Goldstein and D. W. Sweeney, *Los Alamos Scientific Laboratory.*—Using semi-empirical square well interaction forms of the "central force" type, differential and total $n-p$ scattering cross sections have been obtained for neutrons of absolute kinetic energy extending to 90 Mev, with a variety of well radii. The total $n-p$ cross-section data of the Minnesota group, up to 6-Mev neutron energy, when compared with the computed cross sections, seem to favor well radii smaller than the classical electron radius. In the intermediate energy range, 10–25 Mev, data on differential cross sections might help in choosing the most appropriate well radius and the type of interaction representing best the data. Available total cross-section data in this range are insufficient for this purpose, on account of the relative insensitivity of total cross sections to well ranges, at smaller radii and to types of force (ordinary, exchange, or symmetrical). The Berkeley results at 90-Mev neutron kinetic energy, while excluding "ordinary" interaction, are incompatible with either "exchange" or "symmetric" type of interactions for wells with radii from 1.5×10^{-13} cm upward. Empirical "mixtures" of different types of interactions might lead though to a satisfactory representation of these data.

I7. On the Failure of Beta-Decay Theory at Low Energies. Eugene P. Cooper, *University of Oregon.*—The Fermi theory of beta-decay predicts the energy distribution of electrons (or positrons) in any particular nuclear disintegration over the whole range of energies. At high kinetic energy (say above 200 kev), where the predominant energy dependence is in the statistical factor, agreement with unambiguous experiments in excellent. Serious disagreement is encountered, however, at low energies where the Coulomb factor is important. Such disagreement has frequently been attributed to instrumental scattering. However, the recent measurements of Cook and Langer on the electrons and positrons from Cu^{64} are largely free from scattering errors but show definitely too few electrons and too many positrons at low energies. The so-called proof of the Fermi theory given by Scherrer *et al.* with respect to their data on the positrons and K-captures from $Cd^{107,109}$ is shown to be incomplete as their positron spectrum, at low energies, deviates from the theory in the same manner as that of Cu^{64}. In an attempt to explain these low energy discrepancies it is assumed that electromagnetic radiation (x-rays) plays an essential role in the beta-process. The resulting modification of the Coulomb factor is discussed.

I8. Neutron Spectra from Proton Recoils in Photographic Emulsions. F. Reines, *Los Alamos Scientific Laboratory.*—With the coming of nuclear reactors, it becomes interesting to determine neutron spectra for isotropic neutron fluxes. The proton recoil technique rising photographic emulsions may be adapted to this case. Criteria, based on geometrical probability, are provided for the treatment of all tracks which do not touch an emulsion boundary. Emulsion shrinkage is considered. The range energy relation for protons in photographic emulsion is applied to the tracks to yield the neutron spectrum which is related to the proton recoil spectrum by the equation:

$$n(E)=C\lambda(E)E^{\frac{1}{2}}[dm(E)/dE],$$

where C is a constant, $\lambda(E)$ is the mean free path for neutron proton collisions in the emulsion at neutron energy E, $m(E)$ represents the recoil proton spectrum, and $n(E)$ is the desired neutron spectrum. This equation is valid when $\lambda(E)$ is large compared with the dimensions of the photographic plate employed. Work is progressing on a method which considers all tracks independently of whether they penetrate the emulsion.

I9. Radiations from Gold (199).* C. E. Mandeville and M. V. Scherb, *Bartol Research Foundation of the Franklin Institute.*—Au^{199} was grown from its 30-minute platinum parent when platinum was irradiated by neutrons in the pile at Oak Ridge. Aluminum absorption and Feather analysis gave a maximum beta-ray energy of 0.38 Mev, and lead absorption indicated the presence of a single gamma-ray of energy 0.18 Mev. The beta-gamma coincidence rate was constant, independent of the beta-ray energy, and beta-beta coincidences were also present. No gamma-gamma coincidences were found. These data suggest that the 0.38-Mev beta-rays are followed by a single 0.18-Mev gamma-ray which is partially converted. The 1.01-Mev beta-rays, the 0.45-Mev gamma-rays, and the 2.6-day half-period assigned to Au^{199} by Krishnan and Nahum[1] are now attributed to Au^{198} formed in the reaction $Pt^{198}(D, 2n)Au^{198}$.

* Assisted by the Office of Naval Research.
[1] Krishnan and Nahum, Proc. Camb. Phil. Soc. 37, 422 (1941).

I10. The First Excited State of Li^7. W. F. Hornyak and T. Lauritsen, *California Institute of Technology.*—A determination of the energy of the γ-ray accompanying the decay of the lowest excited state of the nucleus Li^7 to the ground state has been made using a magnetic lens type spectrometer. The excited level was reached by non-capture excitation, using 1.2-Mev protons on a LiOH target mounted in the spectrometer. Photoelectrons were ejected from a 0.001″ thick thorium converter. Using the same spectrometer geometry, and source assemblies matching as nearly as possible, the Li^7 γ-ray was compared directly with the 411.1-kev γ-ray[1] from Au^{198} and the 510.8-kev[2] annihilation radiation from N^{13}. With the aid of a calibration based on an internal conversion line in Th B, a study of the energy shift due to the thickness of the converter was made. A shift of 7.0 ± 0.8 kev for the Li^7 γ-ray was found and the energy determined as 479 ± 2 kev. The present value is in good agreement with recent determinations of the γ-radiation from Be^7 by S. Rubin[3] and by A. C. G. Mitchell,[4] but disagrees markedly with the value of 453 ± 5 kev reported by K. Siegbahn.[5] This work was assisted by the Office of Naval Research.

[1] J. W. M. DuMond and D. Lind, in publication.
[2] J. W. M. DuMond and E. R. Cohen, Rev. Mod. Phys. **20**, 82 (1948). We are indebted to Professor DuMond and Dr. Lind for the Au source and for advance information on the γ-ray.
[3] S. Rubin, Phys. Rev. **69**, 134 (1946).
[4] Private communication.
[5] K. Siegbahn, Arkiv. f. Astro., Math., Fys. **34B**, No. 6 (1946).

I11. Gamma-Radiation from $Be^9(d, n)B^{10}$. T. Lauritsen, C. B. Dougherty, and V. K. Rasmussen, *California Institute of Technology*.—Previously reported work[1] on the $Be+d$ gamma-rays has been extended to the upper limit of the spectrum. Using a magnetic lens spectrometer with a resolution of three percent, secondary electrons ejected from Th and Be converters have been studied from <100 kev to 4 Mev. Calibrations were made at 147.6 kev ("F" line from Th B), 411.1 kev (Au^{198}), 510.8 kev (annihilation radiation) and 2.620 Mev (Th C″). At a deuteron bombarding energy of 1.2 Mev the following gamma-ray lines are observed (energies in kev):

411 ± 5	1435 ± 20
475 ± 6	2170 ± 25
718 ± 3	2924 ± 25
1024 ± 10	3425 ± 25

The values obtained agree reasonably well with those derived from neutron groups.[2,3] The most reasonable level scheme would suggest states in B^{10} at 411-, 718-, 1435-, 2170-, and 3425-kev excitation, although the existence of levels at 1024 and 2924 kev cannot be excluded. This work was assisted by the Office of Naval Research.

[1] Lauritsen, Fowler, Lauritsen, and Rasmussen, Phys. Rev. **73**, 636 (1948).
[2] Bonner and Brubaker, Phys. Rev. **50**, 308 (1936).
[3] Staub and Stephens, Phys. Rev. **55**, 131 (1939).

I12. Analysis of the Be^9+p Resonances at 0.988 and 1.077 Mev. E. Richard Cohen and R. F. Christy, *California Institute of Technology*.—An attempt has been made to determine the level assignments of the energy levels in B^{10} indicated by the 0.988- and 1.077-Mev resonances of protons on beryllium previously reported by this laboratory. The observed total scattering cross sections and angular distributions for protons cannot be explained purely on the basis of Coulomb scattering and the two observed resonances, but require the inclusion of a non-resonant nuclear scattering cross section whose magnitude is comparable to that of the Coulomb term. Using a non-resonant cross-section term which, for simplicity, is assumed to be independent of energy or angle, best agreement at the 0.988-Mev resonance is obtained by the assignment $J=1$. The 1.077-Mev resonance seems to be due to incident d-wave protons and the possible assignments to this level will also be considered. This work was supported in part by the Office of Naval Research.

[1] R. G. Thomas, W. A. Fowler, and C. C. Lauritsen, Phys. Rev. **73**, 536 (1948); C. C. Lauritsen, T. Lauritsen, and W. A. Fowler, Phys. Rev. **72**, 739 (1947).

SUPPLEMENTARY PROGRAMME

SP1. The Protected Multicellular Geiger Counter for Short-Wave-Length X-Rays and Gamma-Rays for Use in the Curved Crystal Spectrometer.* David A. Lind, *California Institute of Technology*.[1]—A Geiger counter is described for use in the gamma-ray spectrometer[2] consisting of a series of electrically negative metallic gauze septa placed transversely in a tube together with an alternating series of electrically positive four-pronged "spiders" of 10-mil tungsten wire supported on an axial rod passing through central holes in the septa. The radiation whose photons are to be counted passes axially through this system and ejects electrons from each septum by photoelectric absorption, Compton scattering, and pair formation. The background counting rate from cosmic radiation is markedly reduced by placing above the multicellular counter a battery of six conventional Geiger counters connected in an anticoincidence circuit which suppresses counting by the main counter when any one of the protective counters is excited. This entire system is protected from local radiation other than the beam to be measured by a lead shield 3 to 4 inches in thickness. A mixture of argon with three percent of petroleum ether at 20 cm Hg gives a counting threshold at 1100 volts with a plateau of 200 volts and excellent stability. At 1 Mev a counting efficiency of eight percent of all incident photons is indicated with a counter of five septa and four spiders.

* To be given at the end of Session G if the chairman considers that time permits.
[1] Assisted by the Office of Naval Research.
[2] See companion abstract on this program and also Rev. Sci. Inst. **18**, 626 (1947).