contrast set-up than in an ordinary bright field microscope. In addition, it would be helpful to have known details of form. These two specifications eliminate most natural objects. An artificial object was made using a transparent film on glass put on in such a way as to introduce a quarter-wavelength phase difference over a definite geometric pattern. This cannot be detected in a bright field microscope but shows very plainly in a phase contrast microscope. By the introduction of a suitable amplitude contrast sample on the film, an excellent demonstration object for the phase contrast microscope can be obtained.

77. Effects of Delaying of Germination of Seeds Subjected to Radiation. JUNE G. JONES AND DAVID POMEROY, *University of Florida.*—Experiments at Bikini and elsewhere have shown that when dry seeds are irradiated, their subsequent development is affected.[1] The present experiment illustrates that the extent of radiation damage is influenced by delaying the germination of dry seeds, which have been previously exposed to x-rays. As a measure of the radiation injury, we compared the length which the coleoptiles of the irradiated seedlings attain four days after germination with the length of coleoptiles of control (unradiated) samples.

[1] L. S. Randolph, J. Cell. and Compar. Physiol. **35** (Suppl. 1), 103 (1950).

78. Spectrographic Analysis of Trace Elements in Human Tissues. ISABEL H. TIPTON, *The University of Tennessee, and Health Physics Division, Oak Ridge National Laboratories.*—This is a preliminary report on the program for the analysis of human tissue for trace elements which has been set up in The University of Tennessee Physics Department under contract with Carbide and Carbon Chemicals Company. Autopsy specimens from subjects with a variety of geographical backgrounds are carbonized on a hot plate and ashed in a muffle furnace at 500°C. A sample of the ash is placed in a crater in a spectroscopically pure graphite electrode and burned to completion in a dc arc. A quantitative estimate of the metals observed is made by comparison with standards made by adding known amounts of 23 elements to a biological matrix.

79. Effect of X-Radiation on the Bioelectric Potentials of Rats. DAVID POMEROY AND HERBERT GURSKY,* *University of Florida.*—A modified form of the usual electric millivoltmeter of high input impedance, designed in our laboratories by T. D. Carr,† was used to measure the potential differences between the same points (tip and base of tail) of a specially selected strain of rats. One group was then given 150 r, a second group was given 300 r, while a third group was used as control. The results for individual rats showed no significant difference. Treated statistically, by groups, there is some indication of a fall in p.d. after irradiation, and there is also a difference in the fluctuations as measured by the standard deviations. It has been reported by other investigators that these fluctuations show marked changes at different clinical periods when cancers have been induced on rats.[1]

* Now at Vanderbilt University, Nashville, Tennessee.
† Now with the U. S. A. Guided Missiles Project, Cocoa, Florida.
[1] Burrows, Rose, and Schober, Cancer Research **5**, 524 (1945).

MINUTES OF THE 1952 WASHINGTON MEETING, MAY 1–3, 1952

THE 313th meeting of the American Physical Society, being the 1952 Spring Meeting at Washington, D. C., was held on Thursday, Friday, and Saturday, May first, second, and third, 1952. It achieved a new record in size as measured by number of contributed papers. Three hundred and eighteen abstracts were printed in the Bulletin (three more were deleted because their authors developed qualms, and will be represented by eternal blank spaces in the pages of *The Physical Review*). Invited papers on the general programme numbered twenty-three. Since they are listed hereinafter, I mention only that eleven pertained to nuclear physics comprising cosmic rays, two to cryogenics, three to semi-conductors, four to topics gathered under "chemical physics," and three to a theme new to our symposia, *viz.*, "Entropy and Information." The Division of Electron Physics provided a single half-day symposium, the Division of Chemical Physics a pair.

The thirty-nine sessions among which these offerings were distributed were not too many for the eight halls continuously placed at our disposal, but two of the halls were too small for the crowds; this forebodes either a future limitation or a future spreading-out. The eight were in the Shoreham Hotel, the Wardman Park Hotel, and the National Bureau of Standards: this is the universally popular scheme introduced by the 1951 Local Committee. This year's Local Committee consisted of Hugh Odishaw (Chairman), R. B. Roberts, J. A. Sanderson, S. Silverman, Mrs. C. M. Sitterly, and L. S. Taylor. We owe more than can be expressed in words to them and to their numerous aides—projectionists, "expediters," girls serving at the registration desk—some of whom came from the National Bureau of Standards, some from the Department of Terrestrial Magnetism, some from the Naval Research Laboratory, some from the Applied Physics Laboratory, and some from the Washington Board of Trade. The equipment—lanterns, screens, a movie projector, I know not what more—was provided by the Bureau.

Those who registered at this meeting numbered 1881, against 2150 last year. One spurns the insulting suggestion that the decline was the result of the one-dollar registration fee, at this meeting levied for the first time; neither can it be blamed on the weather, cool and radiant this year as last (some year, however, we shall encounter a heat wave); the best theory is that the members found the sessions so interesting the could not spare the time to register.

The banquet of the Society was held on the Friday evening in the Terrace Room of the Shoreham, with an attendance of 318. (It is a mere coincidence that the number of people at the dinner was the same as the number of ten-minute papers at the meeting.) The after-dinner speakers were S. A. Goudsmit, J. E. Mayer, E. M. Piore, and E. M. McMillan.

The Nominating Committee of the Society met on the Friday afternoon, and here is the list of nominees whose names will appear on the next election-ballot:

Presidency:	Enrico Fermi
Vice-Presidency:	H. A. Bethe
Secretaryship:	K. K. Darrow
Treasurership:	G. B. Pegram
Editorship:	S. A. Goudsmit
Nominees to Council:	Arnold Nordsieck
	L. I. Schiff
	W. Shockley
	J. R. Zacharias

Nominees to Board of Editors, allocation to Physical Review: W. A. Fowler, K. Greisen, C. Kittel, R. E. Marshak, W. K. H. Panofsky, and V. F. Weisskopf.

Nominees to Board of Editors, allocation to Reviews of Modern Physics: R. C. Herman and E. M. Piore.

The Council met on the previous Wednesday afternoon. Here comes the grievous part of these Minutes. Utilizing the powers granted to it by the Society at the Business Meeting of February 1, 1952, the Council set at $20 the 1953 dues for Members and at $30 the 1953 dues for Fellows.

It cannot be too often repeated that this unwelcome action is due to two kinds of inflation: the general economic inflation known to all, and the specific inflation—explosive expansion would be a better term—of *The Physical Review*. The swelling of this journal from 4076 pages in 1950 to 4880 pages in 1951 did not precisely catch us unawares, but it caught us so suddenly that the slow-moving machinery provided by our Constitution could not be started soon enough to enable us to meet the situation betimes by a raise in 1952 dues. Our surplus has been almost eaten up; and not only must we advance our income to the level of our outgo, we must rebuild the surplus and get ourselves into a position to face what emergencies the future may bring.

The assiduous reader (if there is one) of these Minutes will be aware that this is not the first step that the Council has taken of late to restore the Society to financial equilibrium. We have raised the non-member subscription rate of *The Physical Review*, and have increased the page charge for papers and letters appearing in that journal. We have imposed an extra charge on members who wish to subscribe to *Physics Abstracts*. We have instituted a registration fee at our meetings. We have also received a generous grant from the National Science Foundation, from which we may draw for a part of the deficit which *The Physical Review* will assuredly incur in 1952 and may yet incur in 1953. The increase in dues is the last of this series of remedies, and by it we hope and expect that the Society will balance its budget and start to rebuild its vanished surplus. There was, of course, an alternative. We could have limited the size of *The Physical Review* to what we could afford to print under the present budget, accepting the drawback that many worthy papers would have had to be excluded while the publication of others would have been sadly delayed. The Council has proceeded on the assumption that this alternative is not preferred by the members of the Society. It will, however, be adopted in respect of *The Journal of Chemical Physics* if and when this journal is taken overy by the Society, if the choice between the two alternatives has to be made.

An alleviation of the new scale of dues has been granted to students who enter the Society after 1952. They will be allowed to pay on a reduced scale for the first year, and for one more year if they continue to be students. Their sponsors—that is, the members of the Society who sign their nomination forms as sponsors—will be responsible for taking certain steps in order to obtain this concession for the students whom they nominate. Detailed information will be mailed to all of the members of the Society.

According to reports reaching the office of the Society, we have lost through death the following members: H. A. Kramers (Honorary Member), J. J. Downing, W. R. Ham, R. Ladenburg, C. O. Lampland, M. E. Leeds, A. London, and T. B. Staver.

Following are the names of the five candidates elected to Fellowship and the one hundred and twenty-one elected to Membership at this meeting.

Elected to Fellowship: C. S. Cook, F. S. Jastram, G. E. Pake, F. B. Shull, and A. O. Williams.

Elected to Membership: David Aaron, Charles Frederick Andrews, Gaylord Marvin Androes, Stephen Reynolds Arnold, Robert William Astrue, David Bakalar, Adam Becher, Mervin Reamer Beck, Richard Baker Belser, Abraham L. Berlad, Maurice Anthony Biot, Henry Gabriel Blosser, Ralph Raymund Bonkowski, Robert Benjamin Borts, Joseph Charles Bowe, Philip James Bray, Ernst Bruche, Robert Bruce Campbell, Robert James Carbone, Chester Paul Carpenter, Paul Robert Chagnon, H. Malcom Childers, Philipp Choquard, David M. Clarke, Philippe Albert Clavier, John Reid Clement, Jr., Frances Dunkle Coffin, Louis Fussell Coffin, Jr., Richard John Conner, Edward George Cook, Howard Gordon Cooper, Theodore Patrick Cotter, Fernando Jose Corbato, Norman Greig Cranna, Bryce Low Crawford, Jr., Donald Charles Cronemeyer, Herbert David Curchack, Thomas McCaul Dauphinee, Monte Vincent Davis, Sybren Ruurds de Groot, David Alan Dows, Walter George Egan, Tetsuo Eguchi, James Franklin Elliott, Harry Robert Fechter, Mary Jane Fischer, T. G. Fox, Manfred Philip Friedman, Edwin Kilbourne Gatchell, Donald Allen Geffen, Theodore Bruce Godfrey, Bart Austin Goode, Jack Sam Greenberg, Richard Walter Griessel, Norman Michael Gutlove, Peter Hammerling, Robert C. Haymes, Richard H. Helm, Janet Hamilton Henchie, Henry Hoyt Hilton, III, Earl K. Hyde, Ernest Ikenberry, Mark John Jakobson, Charles Lincoln Jewett, Daryl David Keagan, Henry W. Kendall, James Gus Kereiakes, George Bernard Kich, Bruce John Kirby, James Thomas Kouba, Albert William Kratzke, John E. Kreig, Henry Milton Lakin, Michael Francis Lamorte, Mark G. Landisman, William Warner Lang, Jr., Helene Langevin, Edwin H. Layer, Jr., Israel Arnold Lesk, Marvin Burton Lewis, Bruno Linder, William Ivan Linlor, Delmas Carroll Little, Robert James Lovell, Thomas Stephen Mackey, Robert Rudolph Matheson, Fielding Merwin McGehee, Jr., Dean Ervin McMillan, Mukio Miyazaki, Masataka Mizushima, Hiroshi Nakai, Howard Charles Nedderman, John Greenhalgh Parker, Charles Wesley Perkins, Charles Stephen Perry, Jerome Pine, Bernard Frances Poetker, Jr., Edward J. Prosen, Claud Austin Pyle, Alessandro Alberigi Quaranta, Richard Raymond Rau, Donald George Rea, Joseph Hans Rosenbaum, Richard A. Rubenstein, Melvin Michael Saffren, Howard M. Saltsburg, Alvin David Schnitzler, Adam Frank Schuch, Daniel Stanley Schwartz, Arnold E. Seigel, Joseph H. Simons, John David Sorrels, John E. Spalding, George Curtis Sponsler, III, Mathieu Johan Sterk, Gerald Stone, Claude Strother, Jr., Masasi Takasu, William Tobocman, Francis Michael Tomnovec, Helen Mary Ann Urquhart, Basil Christos Vafiades, Arthur Edward Walters, Herman G. Wehe, Harold G. Wenig, Edward Ansil Whalin, Robert Newmann Wiener, and Bruno Zumino.

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

Errata Pertaining to Papers B6, C10, F6, FA5, I7, JA8, L6, N9, PA11, V9, VA3, WA3, WA8, X2, XA2, Y3, Y7, and SP1

B6, by Aaron P. Sanders. A footnote should be added, reading, "This work was supported by the AEC."

C10, by R. S. Ledley. Instead of "R. S. Ledley," read, "R. S. Ledley, DC, U. S. Army, Guest worker at the National Bureau of Standards."

F6, by Peter D. Johnson and Fred E. Williams. In line 13, "traps are isolated Tl^+ in the $^3P_1$ and $^3P_2{}^0$ states," should read, "traps are isolated Tl^+ in the $^3P_0{}^0$ and $^3P_2{}^0$ states."

FA5, by W. C. Porter and W. E. Ramsey. "*Bartol Research Foundation of the Franklin Institute, Swarthmore, Pennsylvania*" should be added to the by-line.

I7, by Richard Schlegel. In line 19, "constant" should read "constancy."

JA8, by R. I. Mendenhall, C. E. Mandeville, E. Shapiro, E. R. Zucker, and G. L. Conklin. In line 12, the phrase "Mc/cm^2" should read "Mg/cm^2."

L6, by Fay Ajzenberg. The title should read "Energy Levels of Be^7 and B^{10}."

N9, by F. M. Kelly and D. K. C. MacDonald. In line 14, "Alternatively, a θ_R rather more accurately descriptive," should read "Alternatively, a θ rather more accurately descriptive."

PA11, by A. M. Bass and W. S. Benedict. In line 12, "$D\rightarrow X$," should read "$D\rightarrow A$."

V9, by W. A. Nierenberg. Reference 1c should read "Davis, Jr., Feld, Zabel, and Zacharias, Phys. Rev. **76**, 1076 (1949)."

VA3, by A. H. Nethercott, A. Javan, and C. H. Townes. The last sentence should be deleted.

WA3, by Thomas A. Perls. In reference 1, "F. T. Rogers," should read "T. F. Rogers." Reference 2 should read, "S. J. Johnson and T. F. Rogers, Phys. Rev. **85**, 714 (A) (1952)."

WA8, by Marcel Martin, Donald H. Jacobs, and Seymour Sholnick. In line 20, "constant pressure," should read "constant temperature."

X2, by L. S. Frost and G. W. Penney. This abstract was withdrawn.

XA2, by F. D. Bennett and G. D. Kahl. Sentence 7 should read, "Conditions are investigated for obtaining perfect plate compensation; these reduce the ellipsoidal interferometer to planar parallelogram form."

Y3, by A. Klein and R. Karplus. The equation should read: $(7/6)\alpha^2 Ry_\infty\{1-(\alpha/\pi)[(32/21)+(6/7)\ln 2]\}=2.034\times 10^5$ Mc/sec.

Y7, by Stewart D. Bloom. The corrected Table I follows.

TABLE I. Observed and theoretical (see reference 2) values of I_1 and I_2.

	Observed value $\times 10^4$	Theoretical values $\times 10^4$
I_1	7.1 ±0.2	11.20 (E2) 6.95 (E2) 4.62 (E3) 5.36 (M1) 3.45 (M2)
I_2	0.6 ±0.1	1.87 (E1) 0.57 (E2) 0.19 (E3) 0.25 (M1) 0.07 (M2)

SP1, by George Antonoff. In line 14, "$d_2=d_1$" should read "d_2-d_1."

PROGRAMME

THURSDAY MORNING AT 10:30

Shoreham, Terrace Room

(R. B. LEIGHTON presiding)

Stars and V-Particles

A1. Stars Induced in Nuclear Emulsions by 100-Mev Protons. RICHARD G. SEED, *Harvard University.*—Ilford G-5 and Kodak NTB3 electron sensitive emulsions have been exposed to the direct and to the internally scattered 100-Mev proton beam of the Harvard cyclotron. Some 150 stars have been analyzed for the angular dependence of the ejected particles. A rough classification of energy, according to grain density is also reported. The resulting angular distributions are interesting for their marked asymmetry, giving forward-to-backward ejection ratios of 3.8 for all tracks from all stars, 3.7 for all tracks from stars of three or more prongs, 3.35 for all tracks of energy less than about 30 Mev, 7.0 for all tracks of energy between 60 and 100 Mev, and 6.3 for all stub tracks (less than 4μ in length). There is also the suggestion of a relative minimum of particles emitted in the forward direction as theoretically predicted by Goldberger.[1] A rough, star collision mean free path of 100 cm (± 15 percent) is obtained, which is rather long, but is uncorrected for zero-prong stars and probably some one-prong stars are missed.

[1] M. L. Goldberger, Phys. Rev. **74**, 1269 (1948).

A2. Stars Induced by High Energy Neutrons in the Light Elements of the Photographic Emulsion.* M. BLAU AND A. R. OLIVER,† *Brookhaven National Laboratory.*—Stratified G-5 emulsions were irradiated with the 300-Mev neutron beam of the Columbia cyclotron and the ratio of stars induced in the light to those in heavy elements has been determined. Assuming that the cross section is a linear function of $A^{\frac{2}{3}}$ the ratio N-light/N-heavy should be 0.27. Counting all stars with ≥ 2 prongs in both emulsion and gelatin layers we obtained N-light/N-heavy$=0.179\pm 0.024$. Because of the uncertainty connected with the recognition of 2-prong stars only 2-prong emulsion stars showing a distinct recoil-fragment were considered. On the other hand, we accepted all 2-prong gelatin stars assuming that in all cases an additional short prong may have been lost in the gelatin. Even though these conditions favor a higher ratio, N-light/N-heavy$=0.213\pm 0.026$ and is still lower than the calculated value, showing increased transparency of light nuclei. If one takes into account the 0-, 1-, and 2-prong stars,[1] N-light/N-heavy would still be further decreased, since for light elements 3- and 4-prong stars are probably favored. The characteristics of gelatin stars will be compared with emulsion stars.

* Research carried out under the auspices of the AEC.
† Now at New York State College for Teachers.
[1] S. J. Lindenbaum, Columbia University thesis, 1951.

A3. Stars Induced by Mu-Mesons in Photographic Emulsions. H. MORINAGA,* *Iowa State College*† AND W. F. FRY,‡ *Iowa State College and the University of Chicago.*§—Ilford C-2 emulsions 400 microns thick were exposed to the 122-Mev external negative meson beam from the University of Chicago cyclotron. The emulsions, shielded from scattered mesons, were placed behind Cu absorbers which stopped essentially all of the π-mesons. A portion of the π-mesons decays in flight into μ-mesons before entering the Cu absorbers. Some of the μ-mesons have a range in Cu one inch greater than the range of the π-mesons. It is thus possible to separate the μ-mesons from the π-mesons quite effectively. About 3 percent of the negative μ-mesons which stopped in the emulsion produced stars with tracks longer than 20 microns. This result is in agreement with preliminary observations reported earlier.[1] A total of 150 stars have been observed, of which 132 have one prong, 12 have 2 prongs, 4 have 3 prongs, and 2 have 4 prongs. The prong distribution[2] and the energy of the charged particles from the meson induced stars indicate that the π-meson contamination is very small. The energy distribution of the protons and alpha-particles has been studied.

* On leave from the University of Tokyo.
† AEC Postdoctoral Fellow.
‡ Supported in part by a grant from the Research Corporation.
§ Supported by a joint program of the ONR and AEC.
[1] W. F. Fry, Phys. Rev. **85**, 676 (1952).
[2] F. L. Adelman and S. B. Jones, Phys. Rev. **75**, 1468 (1949).

A4. On the Analysis of V^0-Disintegrations in Flight.* R. W. THOMPSON, C. J. KARZMARK, AND H. O. COHN, *Indiana University.*—In the analysis of disintegrations in flight of the type $V^0\rightarrow p+\pi+Q$, where the Q values are small, it is pointed out that, although the proton momentum is higher than the meson momentum (in the approximate ratio of the masses) and therefore can be measured with correspondingly less accuracy, the calculated value of Q can be expected to be relatively insensitive to the measured proton momentum in most cases. A qualitative understanding of this result may be obtained as follows: The resolution of the meson momentum π into components π_x and π_y is not sensitive to the measured proton momentum p since the direction of motion of the proton is close to that of the V^0-particle. Therefore π_y' is insensitive to p. However, $c\pi_x'=\gamma_0(c\pi_x-\beta_0 E_\pi)$, where γ_0 and β_0 refer to the V^0-particle, is sensitive to p. From considerations of solid angle, the most probable value of π_x' is zero, and in a majority of disintegrations $\pi_x'<\pi_y'$. Now if β_0 (which is essentially derived from p) is too large, the calculated π_x' is too negative, etc. Thus the calculated Q will usually show a minimum when considered as a function of p, and the effect of large errors in p is usually to raise the calculated Q.

* Assisted by a grant from the Frederick Gardner Cottrell Fund of the Research Corporat on and by the Office of Army Ordnance Research.

A5. Two Examples of V^0-Decay Observed in a Multiple Plate Cloud Chamber.* G. W. CLARK, M. ANNIS, H. S. BRIDGE, H. W. COURANT, AND B. ROSSI, *M.I.T.*—With a multiple plate cloud chamber operated at ten thousand feet and triggered by a penetrating shower detector located above the chamber, several V^0-decay events have been photographed. One example shows two tracks of minimum ionization diverging from a point in the gas with an included angle of 3.7°. Both tracks traverse several lead plates scattering less than 1° per plate. One track ends in an interaction which produces a multicore electron shower with no apparent associated penetrating particles. This shower develops to at least 20 particles before passing out of the chamber. The other track cannot be followed beneath a lead plate where it may be lost in the electron shower. The second example shows an event which occurs in a lead plate and in which an ionizing particle produces a V^0 and one heavily ionizing particle of short range.

The V^0-decays in the gas and gives rise to two lightly ionizing particles which diverge at wide angles from the direction of flight of the V^0.

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

A6. General Properties of V^0-Particle Decay.* C. D. ANDERSON, R. B. LEIGHTON, F. H. SHELTON, AND S. D. WANLASS, *California Institute of Technology*.—In 25,000 cloud-chamber photographs (magnetic field 5000 gauss) taken at sea level and at 5700 ft in a study of penetrating showers, 136 V^0-particle decays were observed.† More than 80 percent of the decays yield a light negative and a heavy positive particle. Where mass measurements are possible, these indicate that the negative particle is most often a π-meson but in some cases is probably a μ-meson; the positive particle mass is often consistent with that of a proton, but sometimes seems somewhat lower (1200–1500 m_e). In nine cases the mass of the positive particle is less than 700 m_e, and in one of these the negative is greater than 1100 m_e. There is little evidence that directly suggests a decay into two π-mesons,[1] although a few cases may be so interpreted. In the 55 cases where the origin of the V^0 could be located, measurements of "coplanarity" and transverse momentum-balance are consistent with a two-body decay, but do not exclude certain other decay schemes, e.g., a cascade decay through an intermediate particle of short lifetime and low excitation.

* Supported in part by the joint program of the ONR and AEC.
† Seven V^+ and eleven V^- decays were also seen, most of which yield charged secondaries of mass less than 500 m_e.
[1] Armenteros, Barker, Butler, and Cachon, Phil. Mag. **42**, 1113 (1951).

A7. Energy Release in V^0-Decay.* S. D. WANLASS, R. B. LEIGHTON, W. L. ALFORD, C. D. ANDERSON, AND F. H. SHELTON, *California Institute of Technology*.—The energy release, or Q value, of V^0-decay was calculated for 88 of the cases of the above abstract. A two-body decay into $\pi+p$ was assumed for those cases which clearly indicate the presence of a heavy positive particle. The Q values so obtained range from 10 Mev to over 250 Mev. A great majority of cases can be described in terms of two discrete Q-values, at 35±3 Mev and 75±5 Mev, but not in terms of a single Q value near 45 Mev,[1] because several cases of especially high quality seem to exclude the latter possibility. A continuous distribution with or without some discrete values cannot, of course, be excluded. It should be mentioned that, if the positive particle is assumed to be even as light as a κ-meson ($\sim$1250 m_e) and/or the negative particle, a μ-meson, the distribution of Q values is not greatly changed, and the apparent necessity for at least two Q values remains.

* Supported in part by the joint program of the ONR and AEC.
[1] Armenteros, Barker, Butler, and Cachon, Phil. Mag. **42**, 1113 (1951).

A8. Production of V^0-Particles.* F. H. SHELTON, S. D. WANLASS, AND R. B. LEIGHTON, *California Institute of Technology*.—In 32 of the above cases, the V^0-particle was produced in a nuclear event in a 2.5-cm thick lead plate inside the cloud chamber. Four of these events were initiated by neutral particles, four by charged particles occurring alone, and 24 by charged particles which were themselves secondary particles from nuclear events occurring in the lead above the chamber. The relative numbers produced by neutral and by charged particles suggest that the majority of V^0-particles are produced by mesons rather than by nucleons. The angular distribution of the V^0-paths with respect to the direction of the initiating particle is essentially constant from 0° to 20°, where it drops sharply by about a factor of three, and again is essentially constant to about 50°, beyond which no cases have been found. This suggests the presence of two types of V^0-particles, and a preliminary analysis indicates that the group with the higher cut-off angle is identifiable with the 35±3 Mev group of the previous abstract. The energies of the initiating particles, estimated by various methods, range from at least 5 Bev to more than 25 Bev.

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

THURSDAY MORNING AT 10:30

Shoreham, Main Ballroom

(E. M. MCMILLAN presiding)

Apparatus of Nuclear Physics

B1. An Electron Cyclotron (Microtron) for 3-cm rf Operation. H. F. KAISER, *Naval Research Laboratory*.—The microtron, an electron accelerator first proposed by Veksler and by Schwinger, and first successfully operated in the 10-cm rf band by Redhead, McCain, and Henderson,[1] has the possibility of development as a very compact electron accelerator. Designating the ratio E_f/r_f (final total electron energy/final orbit radius) as a quality factor for compactness, then

$$E_f/r_f \sim H \sim \frac{1+C_1}{T_0 M} \sim \frac{C_2}{T_0(N-M)},$$

where T_0 is the fundamental rf period, M the integral number of fundamental periods in the first (injection) orbit N that for the first orbit after injection, and C_1 and C_2 the energy fractions of $E_0=M_0C^2$ imparted to the electron in the respective orbits. E_f/r_f can be improved by decreasing T_0 and increasing C_1 and C_2 subject to limitations set by electron radiation and by pulsed magnetron power sources operating into cavity resonators. The above will be discussed together with changes required for operation in nonuniform (focusing) magnetic fields. A description of a 3 cm microtron and results obtained to date will be given.

[1] Redhead, McCain, and Henderson, Can. J. Research **23A**, 73 (1950).

B2. Theoretical Study of a Modified Cockroft-Walton High Tension Generator. PAUL LORRAIN, *University of Montreal*, EDGAR EVERHART, *University of Connecticut*, AND RENÉ A. BÉIQUE, *University of Montreal*.—The output voltage at no load, taking into account the stray capacities of the rectifiers, has been calculated by considering the voltage multiplying circuit as a lumped-parameter transmission line. The calculations give the inverse voltage on the rectifiers, the rf currents in the condensers and the input capacity. It is shown that the output voltage can be increased considerably by loading the circuit at the high voltage end with a coil of the proper inductance. the rf is fed push-pull to the voltage multiplying circuit and the high tension is drawn from a center-tap on the loading coil. The voltage gain and the efficiency of the input rf transformer have also been calculated.

B3. New Equipment and Methods Used with the Argonne Fast Neutron Chopper. L. M. BOLLINGER, S. P. HARRIS, AND R. W. SCHUMANN, *Argonne National Laboratory.*—A new 100-channel time analyzer has been put into operation for measuring the time of flight of the neutrons issuing from the Argonne fast neutron chopper; the analyzer has been in use for two months without revealing any basic weaknesses in conception or design. The fundamentals governing its operation, which n principle result in exactly equal channel widths, will be discussed. A new chopper, with properties similar to the Argonne chopper previously described,[1] is also in use. The greater neutron flux passed by this chopper and the reliability of the new time analyzer now make it feasible to use a neutron flight path that is longer than the 10 meter path employed until recently. Difficulties that are produced by a longer flight path will be discussed and some neutron transmission measurements using a 20-meter flight path, which results in a resolution of 0.5 μsec per meter, will be given.

[1] W. Selove Phys. Rev. **84**, 869 (1951).

B4. A First-Order Theory for the Ion Optics of Van de Graaff Accelerators.* M. M. ELKIND,† *M.I.T.*—The design of ion optical systems for long high voltage tubes has relied upon experimental work which usually did not distinguish between the source and tube optical properties. McKibben[1] first recognized and described the tube's optical elements. This analysis is based upon a more accurate description of these elements leading to nondimensional relationships for focusing, magnification, and the radius of the beam along the tube. The need for a similar description for the source and its electrodes is shown, and a method of analyzing a simple versatile source system is given. The theory is illustrated by its application to the Rockefeller accelerator at M.I.T., leading to computed focusing voltages agreeing with those used. This work was undertaken for, and successfully applied to, the recently completed ONR accelerator at M.I.T.

* This work has been partially supported by the joint program of the ONR and AEC.
† From Biophysics Section, National Cancer Institute Bethesda, Maryland.
[1] J. L. McKibben, LADC Report No. 604 (1949).

B5. An rf Ion Source with Transverse Magnetic Field.* J. S. SWINGLE, JR.,† AND C. P. SWANN, *Bartol Research Foundation.*—An rf ion source operating with a transverse magnetic field has been developed for use in the Bartol Van de Graaff accelerators. The transverse field is of the order of 9 gauss and is obtained from permanent magnets. The rf is about 25 mc. The application of the magnetic field reduces the power required by the oscillator to about 40 percent of the power required without the field. Sixty microampere beams, 80 percent of which were protons, have been obtained on a bench set-up, the gas flow being less than 1 cc per hour. Initial tests of the ion source in one of the Bartol accelerators resulted in 30 microamperes of total current focused into a spot about $\frac{1}{16}$ in. in diameter. The voltage on the machine during this test was approximately 500 kv. The power supplied to the oscillator in this case was only 85 watts.

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

B6. A Monitor for Low Intensity Beta-Radiations. AARON P. SANDERS, *Brookhaven National Laboratory.*—A beta-sensitive radiation monitor has been constructed for use in studying the argon-41 activity, at nearby points, due to the cooling air from the Brookhaven Pile. The chamber of the existing Dynamic Condenser Electrometer[1] has been modified to have a wall density of 3.5 mg/cm². The beta-sensitive instrument has been calibrated in a closed room using Pile activated argon-41. An analytical treatment has been used to allow for the finite size of the room, the correction being only 0.5 percent. A correction was made for leakage of A^{41} from the room. The monitor is found to have a beta-sensitivity of 20.0μ-rep/cycle of the recorder and a gamma-sensitivity of 4.85μ-rep/cycle. Beta-dosage rates from 1.0μ-r/hr to 1400μ-r/hr may be measured. Further modification of the electrometer would allow an extension of range. A summary of beta-background data and a comparison of field data with meteorological dosage calculations will be given.

[1] J. B. H. Kuper and R. L. Chase, Rev. Sci. Instr. **21**, 356–359 (1950).

B7. Thermal Neutron Flux Distribution in the Oak Ridge Uranium-Graphite Reactor. HARRY H. HUBBELL, JR., *Oak Ridge National Laboratory.*—With the cooperation of the Oak Ridge School of Reactor Technology, a method has been devised for making a rapid survey of the thermal neutron flux in certain holes in the Oak Ridge National Laboratory Natural Uranium-Graphite Reactor. A 10-mil copper wire is drawn rapidly into the reactor by a rabbit in the fast pneumatic tube, or lowered with a weight on the end into a vertical hole. The wire is irradiated for half an hour, then reeled out onto a special lead-shielded reel. The decay of the five minute half-life Cu^{66} is followed for an hour to check the linearity of the instruments, then the wire is pulled slowly and uniformly past a beta-proportional counter. The counting rate due to the 12-hour half-life Cu^{64} as a function of position is plotted directly by a special linear scale count rate meter driving a chart recorder. The recorder thus plots the flux of neutrons, chiefly thermal, which activate the Cu^{64} as a function of position in the reactor. The cosine distribution, a large depression in flux due to a control rod, and the small depressions due to the metal slugs show up very plainly.

B8. Irradiation Chamber for 100-Curie Cobalt 60.* M. A. GREENFIELD, L. B. SILVERMAN, AND R. W. DICKINSON, *University of California at Los Angeles.*—A chamber has been designed and built to house a 100-curie source of cobalt 60. The chamber and cobalt source are to be used to irradiate chemical or small biological samples. The main features achieved are the following: (a) Over-all size and weight: $3\frac{1}{2}$ ft diam$\times 4\frac{1}{2}$ ft high; 8 tons. (b) Basic lead thickness for shielding: $8\frac{1}{2}$ in. (c) Size of working space: cylinder with 22-in. diam, 12 in. high. (d) Size of access door: 9 in.$\times$11 in. (e) Position of cobalt source: (in use) centrally lowered from top, giving 360° availability for samples; (in storage) removed to turret above working space. (f) Radiation levels for personnel: (in use) average reading at external surface of chamber is 1 mr/hr; (in storage) average reading at external surface of chamber is background. (g) Radiation levels for samples: 30 r/min to 5000 r/min. (h) Time required to load or unload samples: 10 to 15 sec.

* This report is based on work performed under Contract between the AEC and the University of California at Los Angeles.

B9. A Thirty-Channel Pulse-Height Discriminator Based on a Cathode-Ray Tube. H. W. FULBRIGHT AND J. A. MCCARTHY, *University of Rochester,* AND C. W. MCCUTCHEN, *Brown University.*—A thirty-channel differential pulse-height analyzer for use in nuclear investigations has been built, and after being tested in operation over the past eight months has been found to be very satisfactory. Its design is based upon the stability of the deflection characteristic of a cathode-ray tube operated under constant accelerating and focusing voltage conditions. The incoming pulse is shaped, then applied to the vertical deflection plates of a 5RP11A tube, whose beam is normally kept cut off by negative grid bias. After the maximum of the shaped pulse has arrived, an intensifier signal turns on the beam and the bright spot moves down the screen to its undeflected position, passing behind a series of opaque strips so distributed that the number of light flashes emerging is proportional to the height of the incoming pulse. A photomultiplier transforms the flashes into electrical pips which are counted by a fast scale of 32 counter, whose state is then sampled by coincidence circuits which cause the appropriate channel to record an event. Reset impulses then return the instrument to its normal state. Additional channels recording the total number of incoming pulses and the number of oversized pulses are included.

B10. The Construction and Operation of a High Pressure Diffusion Cloud Chamber.* JAMES M. WYCKOFF,† *University of Rochester.*—A diffusion cloud chamber has been built of stainless steel with Herculite glass windows capable of operating at pressures up to 50 atmospheres. Cosmic-ray tracks of excellent quality have been observed with methanol vapor in helium at 35 atmospheres and only a slight reduction in quality was noticed at 50 atmospheres. Cosmic-ray tracks of excellent quality have also been observed in hydrogen at 50 atmospheres. Though many aspects of Schutt's theory[1] are observed to hold, these pressures are well above the predicted limiting pressures. Sensitive depth remained about two inches in the six-inch-deep chamber. The reduction in vapor availability as well as an increase in the number of ion pairs per unit track length with pressure increase was evidenced in several ways. Some of the construction features of this chamber will be discussed including a discussion of the roll of a clearing field in a diffusion cloud chamber.

* Research supported in part by the AEC.
† Now at the National Bureau of Standards, Washington, D.C.
[1] See R. P. Schutt, Rev. Sci. Instr. 22, 730 (1951).

B11. Loading of Photographic Emulsions with Light Elements.* S. GOLDHABER AND G. GOLDHABER, *Columbia University.*—Ilford G-5 nuclear emulsions loaded with H_2O, D_2O, and glycerine ($C_3H_5(OH)_3$) have been found to retain their property of recording minimum ionization particles. Water and heavy water were introduced by the well-known "soaking technique"; however, the introduction of glycerine required a presoaking in water followed by a prolonged immersion in glycerine. The introduction of glycerine provides a method of increasing the relative concentration of the carbon, hydrogen, and oxygen content of the emulsion (a weight percent increase up to a factor of 2 can be obtained). Such plates prove to be stable for several days. The calculated range as a function of glycerine content was checked with mu-meson tracks from the pi-mu-decay and better than 5 percent agreement was obtained. One gram of glycerine/cm^3 of dry emulsion changes the mu-meson range from 597 to 730 microns.

TABLE I. Typical soaking data for 600 μ-Ilford G-5 emulsions.

Soaking medium	Quantity introduced	Presoak time hr	Presoak temp °C	Soaking time hr	Soaking temp °C	Swelling factor
H_2O	1.46 g	...	...	2	10	2.3
D_2O	1.23	...	...	2	10	2.0
Glycerine	1.14	15	17	16	17	1.8

* This work was performed under the joint program of the AEC and ONR.

B12. A Fast Neutron Scintillation Spectrometer. JAMES E. DRAPER AND BOYCE D. MCDANIEL, *Cornell University.*—A coincidence spectrometer is being tested to measure complex spectra of 2–20-Mev neutrons. Proton recoil pulse heights in the first of two 1.25 in.×0.75 in. stilbene crystals are measured in coincidence with a pulse in the second, the coincidence and source-crystal geometry defining the neutron scattering angle. A 3×10^{-8} sec coincidence circuit affords a negligible chance coincidence rate. At 45° with a geometrical resultion of 20 percent full width the fraction of first crystal recoils producing coincidences is calculated as 0.8×10^{-3}. The instrument was tested with Co^{60} gamma-rays for resolution, resolving time, effect of the cyclotron magnet and the rf. Then it was tested with monoergic 15-Mev $T^3(d, n)$ and 2.5-Mev $D(d, n)$ neutrons from the little cyclotron. With a 15 percent channel width the full width at half-maximum of the $T^3(d, n)$ peak has been 3 channels—somewhat greater than the geometrical plus photomultiplier width. This peak shifted in energy with neutron recoil angle in the expected manner. The competing effects of gamma-ray background were found small with Pb and paraffin absorbers of equivalent thickness for gamma-rays.

THURSDAY MORNING AT 10:30

NBS, Chemistry Lecture Room

(J. G. KIRKWOOD presiding)

Chemical Physics, Biophysics, General Physics

C1. Equilibria in Liquids. II. Liquid-Vapor Systems. GEORGE ANTONOFF.—Whereas separation into two liquid layers with the formation of the complex Z is very rare, pure liquids follow its pattern universally. Properties of liquids *versus* temperature invariably exhibit "kinks."* In conditions of equilibrium the kinks are reproducible. Equilibrium is easily attained if liquids contain gases or other matter dissolved in them. Liquids deprived of gases are liable to remain in oversaturated states and do not show normal characteristics. Thus, the freshly purified liquids should not be used for these experiments. Dilatometric method is not recommended, because gases break the column in the capillary. If liquid stands several days in the thermostat, it acquires normal properties. In equilibrium, kinks will invariably appear in the same places corresponding to simple values of X, showing that we deal with a true law of nature. The complexes formed at the kinks are held together by van der Waals forces only and thus have no stability of chemical compounds. They cannot be separated—they can only exist in equilibrium conditions. We designate them by the name aggregates.

* Compt. rend. 3/XII (1951); J. Chim. Phys. (Paris) (February, 1952).

C2. The Forces between Acetone Molecules. VERNON MYERS. *The Pennsylvania State College.*—The long-range forces between acetone molecules are calculated from the dipole moment and optical dispersion data, and the short-range repulsive forces are estimated from second virial coefficients. The long-range forces are given by $V=-4.69(R^{-3}+R^{-5})(2\cos\theta_1\cos\theta_2-\sin\theta_1\sin\theta_2\cos\phi)-(533R^{-6}+1210R^{-8})$ ev, R in A. R is the distance between molecular centers; θ_1 and θ_2 are the angles between the respective dipoles and R, and ϕ is the relative azimuth for the dipoles. The term in R^{-5} is included to account approximately for dipole-quadrupole interactions. If the repulsive forces are approximated by a hard sphere model, a molecular diameter of 4.35A gives the best agreement with experiment. Results will also be shown for an exponential repulsion.

C3. Separation of Trace Elements in Minerals with Resin Ion Exchange Columns. L. T. ALDRICH, L. F. HERZOG, P. H. ABELSON, AND E. T. BOLTON, *Carnegie Institution of Washington.*—To the physicist the problem of separating trace quantities of any element from bulk minerals for mass spectrometric analysis is usually sufficient to insure collaboration with a chemist. Our particular interests were in completely separating Rb from Sr, K from Ca, and Sr from Ca in order that analyses may be made on Rb, Ca, and Sr samples of 50 μg or less. Two problems make these separations essential. One is that of interference in the mass-spectrograph measurement of Sr and Ca due to small amounts of neighboring alkali metals always found in standard separations of Groups I and II of the periodic table. The other is that of saturation in the ion source with resultant loss of sensitivity when the element to be analyzed is 1 percent or less of the sample to be analyzed even if the sample is all Group I or Group II. Resin ion exchange columns have been shown to be especially useful in separating the rare earth elements. Separations of the alkali metals and alkaline-earth metals within each group have been reported. The methods within the two groups were enough different that they could not be applied to separation between the groups. We have worked out a simple procedure for separating (a) Groups I and II from the bulk mineral, (b) Groups I and II from each other, and (c) the elements within each group, using resin columns with various properties. These methods have been used in a routine procedure to extract Sr to study the variation of the isotopic abundances of Sr in the minerals, biotite, celestite, and lepidolite.

C4. The Energy Requirements for Bacterial Motility. HAROLD J. MOROWITZ, *National Bureau of Standards.*—The power, P, necessary to sustain bacterial motility in an aqueous medium is given by the following expression:

$$P=\frac{6\pi v^2\eta(ab^2)^{\frac{1}{3}}(1-\rho^2)^{\frac{1}{2}}}{\rho^{\frac{2}{3}}\ln\dfrac{1+(1-\rho^2)^{\frac{1}{2}}}{\rho}},$$

where v is the velocity of the bacterium, η the viscosity of the medium, b the equatorial semi-axis, a the semi-axis of revolution, and ρ the ratio b/a. Substituting the experimentally observed values for *B. subtilis* and correcting approximately for the drag of the flagella and the inefficiency of the process, the total power required is about 75 electron volts per second. The motile energy is assumed to come from high energy phosphate bonds ($\Delta F\sim 0.4$ ev). Approximately 200 high energy bonds are therefore required per second to maintain the motion. The bacterium under consideration has between 10 and 20 flagella which flick between 10 and 20 times a second or a total of between 100 and 400 flagellar flicks per second. The correspondence of this number to the number of bonds reacting per second makes plausible the hypothesis that each flagellar flick is the result of the metabolic hydrolysis of one high energy phosphate bond. This would provide a unique case in which the reaction of a single chemical bond could be followed by observing its end effect in a biological system.

C5. Inactivation of Southern Bean Mosaic Virus by Deuterons. E. C. POLLARD, *Yale University** AND A. E. DIMOND, *Connecticut Agricultural Experiment Station.*—Studies of southern bean mosaic virus in solution indicate that it is quite accurately spherical, with radius 149A and an internal hydration of 0.57 gram of water per gram of dry virus. When dried for the purpose of electron micrographs the radius shrinks to about 125A but the spherical shape is retained. In view of the fact that bacterial viruses show a relatively small cross section for inactivation by deuterons, while tobacco mosaic virus has nearly its whole area sensitive to deuteron passage, a trial for a second plant virus is of interest. The results show that the cross section is 3.8×10^{-12} cm^2 for a deuteron of 3.5 Mev. The equivalent radius, together with some comparative values for other viruses are given in Table I.

TABLE I.

Virus	Electron micrograph dimension	Deuteron cross section
TMV[2]	100A×2800A	120A×2200A
SBMV	125A radius (head)	110A radius
T-1 phage	250A radius (head)	118A radius
T-3 phage	225A radius (head)	127 radius
T-7 phage	225A radius (head)	115 radius

It begins to appear, therefore, that plant viruses have a greater radiation sensitivity per unit volume than bacterial viruses.

* Assisted by the AEC.

C6. On the Size, Shape, and Hydration of Tomato Bushy Stunt Virus. PAUL KAESBERG, *Department of Biometry and Physics*, AND J. A. ANDEREGG, B. R. LEONARD, AND W. W. BEEMAN, *University of Wisconsin.*—We have measured the angular distribution of x-rays scattered from dilute solutions of tomato bushy stunt virus in order to determine the size and shape of the virus in solution. These results were compared with sedimentation, diffusion, and electron microscope data to determine hydration. The x-ray data show that the virus in solution is nearly spherical, having a diameter 320±10A. The scattering curve beyond the third maximum does not agree with the theoretical curve for spheres of uniform electron density indicating that the particles may not be of constant density. The volume corresponding to a 320A sphere is $17.2\cdot10^6\ A^3$. The volume of the dried virus material as determined by sedimentation and diffusion and also by microscopy is $12.3\cdot10^6\ A^3$. The difference in these volumes—$4.9\cdot10^6\ A^3$—is the volume occupied by water in the interior of the virus. Since the volume in solution is greater than the volume of the dried particle as determined by microscopy, the virus must shrink when drying, rather than maintaining a rigid structure as the water is removed. We are indebted to Professor Robley Williams for giving us some of his purified virus preparations.

C7. Small-Angle X-Ray Scattering from Serum Albumin Solutions. J. W. ANDEREGG, W. W. BEEMAN, *Department of Physics* AND S. SHULMAN, *University of Wisconsin.*—An investigation has been made of the angular distribution of x-rays scattered at small angles by dilute solutions of bovine and human serum albumin (mercaptalbumin). A rotating anode x-ray tube and slit collimating system provided an intense beam with low background and permitted measurements to be extended to very dilute systems. This was found important in eliminating interparticle interference effects. The slope of the scattering curve at the smallest angles gives the radius of gyration of the scattering particle. When extrapolated to infinite dilution the results for the radii of gyration of human and bovine serum albumin are 31A and 29A, respectively. Taking an average value of 30A and a molecular weight of 69,000 and assuming an ellipsoidal model this result indicates an axial ratio of 3.5 to 1 if the molecule is prolate and 1 to 5 if oblate. The data at larger angles give an independent check of the particle shape and agree best with an oblate ellipsoid of about axial ratio 4. This could indicate that the molecule swells in solution. Other interpretations, including the possibility of a real difference between bovine and human serum albumin, will be discussed.

C8. Interferometer Method of Recording Sedimentation in the Ultracentrifuge.* A. ROBESON, N. SNIDOW, AND J. W. BEAMS, *University of Virginia.*—Two sector shaped cells mounted side by side in the ultracentrifuge rotor are sealed by the same pair of quartz windows. Monochromatic light from a timed spark is split into two beams, one of which passes through the first cell containing the solution where sedimentation takes place while the other passes through the second cell which contains the solvent only. The two beams then are recombined to form interferometer fringes. The beam splitter consists of a half silvered and a full silvered mirror with their silvered surfaces parallel. The beams are recombined by a similar arrangement except the two surfaces may be slightly tilted with respect to each other. By proper adjustment the ultracentrifuge cell and the fringes are focused sharply on the photographic plate. A second pair of cells containing the solvent only are mounted in the rotor in place of the usual dummy. This provides reference fringes from which the fringe shifts due to sedimentation are measured. Strains in the windows are approximately compensated and high precision is obtained.

* Supported by Navy Bureau of Ordnance.

C9. Radiation Loss from the Atmosphere.* GILBERT N PLASS, *The Johns Hopkins University.*—The radiation loss from a layer of the atmosphere can be calculated in principle from the intensities and positions of the spectral lines. In practice such factors as the different line intensities and half-widths; the overlapping of the lines; the asymmetry and shift of the lines; the dependence of half-width on pressure, make accurate theoretical calculations difficult. However, starting from the results of laboratory absorption experiments, it is possible to derive the radiation loss from the atmosphere, taking into account all the factors mentioned above that cause difficulty in the usual theoretical treatment. A simple integration of the absorption data gives the radiation loss directly. The only approximations made in this derivation are to neglect the temperature dependence and to assume that the band can be divided into various frequency intervals, each of which contains predominately weak or strong lines. A line is termed "strong" when the dimensionless quantity γ, introduced by Strong and Plass,[1] is greater than one. It is possible to decide experimentally when this approximation is valid. Applications to the CO_2 and H_2O bands will be discussed.

* This work was supported by the ONR.
[1] J. Strong and G. N. Plass, Astrophys. J. **112**, 365 (1950).

C10. The Relation of Tooth Surfaces to the Stability of Artificial Dentures. R. S. LEDLEY.—It is estimated that between 1 and $1\frac{1}{2}$ million dentures are made in the United States yearly. Perhaps the most important requirement of artificial dentures is stability under the forces of mastication. The direction of forces of food on surfaces of denture teeth during physiologic chewing processes presents a real biophysical problem greatly influencing denture stability. It has been demonstrated that the direction of these forces with respect to the horizontal is

$$\tan F = \frac{K\tan S + \tan(M-S)}{K - \tan(M-S)\tan S},$$

where S is the mean slope of the tooth surface, M, the direction of jaw movement during chewing, and K, a constant. However, the direction of motion during chewing is given by the patient's habits, and the force direction thus depends on the setting of the tooth surface slope. For given direction of chewing, M, the tooth surface slope must be between $\tan S = (\frac{1}{2})[(1-K)\tan M \pm ((1-K)^2\tan^2 M - 4K)^{\frac{1}{2}}]$ so that the resulting force will tend to stabilize the denture.

THURSDAY MORNING AT 10:30

NBS, Materials and Testing

(R. J. DOLECEK presiding)

Invited Papers in Cryogenics

CA1. The Isotope Effect in Supraconductivity. E. MAXWELL, *National Bureau of Standards.* (30 min.)

CA2. Paramagnetism below 1°K. DIRK DE KLERK, *University of Leiden.* (30 min.)

THURSDAY MORNING AT 10:00

Shoreham, West Ballroom

(G. BREIT presiding)

Nuclear Theory

D1. On the Process of Binary Fission. T. D. NEWTON, *Chalk River Laboratories.*—The fission process is described by the usual nuclear parameters. The basic assumption required is that from the stage just preceding complete separation the fragments have characteristics sufficiently definite for their motion to be described by a wave equation. The reduced fission width is supposed to be the same for all modes of interest. The penetration factor, which arises because the fragments still have to penetrate a Coulomb barrier, is critical and must be evaluated taking into account the large values of Kr and $ZZ'e^2/\hbar v$. The total width for production of fragments of a given mass ratio involves a sum over the energy states of the fragments. Near the effective threshold the resultant width function varies like the experimental thermal fission yield curve. The small corrections needed are obtained from the additional stability of magic number nuclei. This shape is extremely sensitive to energy and symmetrical fission becomes most probable at energies slightly above the effective threshold. Since fission is a slow process, a highly excited nucleus will first evaporate neutrons; subsequent fission will tend to become symmetrical as the ratio Z^2/A increases.

D2. Detection of Nuclear Magnetic Octopole Interaction.* JOHN LEVINSON, *Alfred University*.—Results are presented of a search for elements most likely to show nuclear magnetic octopole interaction in atomic beam magnetic resonance experiments. They are largely negative. The work of Casimir and Karreman[1] was combined with the method of Goudsmit[2] to obtain octopole-to-dipole interaction ratios for various normal and metastable states. States having a special type of axial symmetry could have finite octopole interaction with zero dipole interaction. No such states were found. It should be noted, however, that elements do have higher interaction ratios if they have (1) high atomic number, (2) p valence electrons, and (3) high nuclear and electronic angular momentum quantum numbers. Thus, bismuth is favorable according to the above criteria. Indium is another good choice, yet Mann and Kusch[3] found no significant octopole interaction. This may simply mean that indium nuclei have little or no octopole moments.

* Work begun at M.I.T. Completed at Alfred University with assistance from the Alfred University Research Foundation.
[1] Casimir and Karreman, Physica **IX**, 495 (1940).
[2] S. Goudsmit, Phys. Rev. **37**, 663 (1931).
[3] A. R. Mann and P. Kusch, Phys. Rev. **77**, 427 (1950).

D3. On the Theory of Nuclear Reactions. H. FESHBACH, C. PORTER, AND V. F. WEISSKOPF, *M.I.T.*—The theory of the compound nucleus assumes an immediate coagulation of the incident particle with the target nucleus in a nuclear reaction. This assumption leads to an approximate proportionality of neutron width to level distance and to a definite expression $\bar{\sigma}_t$ for the total cross section as function of energy in disagreement with experiments by Barschall and coworkers. In fact, these experimental results resemble curves expected from a scattering by a simple potential hole. We investigated the following modification of the compound nucleus hypothesis: We assume that the incident particle moves within the nucleus freely in a potential hole and that there exists a probability P for the formation of a compound nucleus during one traversal. The original theory corresponds to $P=1$. For intermediate P, the total cross section lies between $\bar{\sigma}_t$ and the potential hole values. This is in agreement with experiment. The neutron width is increased relative to the original theory in the region where the total cross section is larger than $\bar{\sigma}_t$ and decreased in the opposite case. Hence, evidence may exist for slower formation of the compound nucleus than has hitherto been assumed.

D4. Neutron Inelastic Cross Sections for Excitation of Single Levels of Middle-Weight Nuclei. JAMES E. MONAHAN,* *Argonne National Laboratory*.—Feld *et al.*[1] have derived an expression for the inelastic cross section for excitation of a particular level of middle-weight nuclei which can be applied rather simply to (n, n) reactions in which only one or two levels of the residual nucleus are excited. The published calculations[1] based on this expression are limited to extremely unfavorable nuclear transitions at comparatively low energies; the resulting inelastic cross sections are negligibly small compared with the corresponding total cross sections. These calculations have been extended to include more favorable transitions at higher neutron energies; the resulting single level inelastic cross sections ($\sim$0.1 to 1.0 barn) represent an appreciable fraction of the total cross section in most cases. Also cross sections for excitation of two levels have been calculated as a function of the energy of the incident neutron for two combinations of level parameters.

* On leave from St. Louis University, St. Louis, Missouri, under the participating institution program.
[1] Feld, Feshbach, Goldberger, Goldstein, and Weisskopf, "Final Report of Fast Neutron Data Project," USAEC Report NYO-636.

D5. Direct Interaction and Compound Nucleus for 14-Mev Neutrons. H. MCMANUS AND W. T. SHARP, *Chalk River Laboratories*.—For elements with $A>80$, (n, α) and (n, p) cross sections at 14 Mev are[1] orders of magnitude larger than predicted by the Weisskopf theory,[2] while $(n, 2n)$ cross sections are[1] essentially in agreement. This suggests that an incoming 14-Mev neutron has a significant chance of interacting directly with the individual nucleons in the target nucleus without formation of a compound system. We have made estimates of the cross section due to such an effect using a square well individual particle model for the nucleus and a perturbation calculation similar to that of Courant.[3] The results are insensitive to the choice of nuclear parameters but depend critically on the reaction Q values. A 5 to 10 percent probability for such a direct interaction suffices to explain the observed (n, p) cross sections: For $A<80$ the compound nucleus contribution to the cross section predominates.

[1] E. B. Paul and R. L. Clarke, Bull. Am. Phys. Soc. **27**, No. 1, 30 (1952).
[2] Blatt and Weisskopf, M.I.T. Technical Report, No. 42 (May, 1950).
[3] Ernest D. Courant, Phys. Rev. **82**, 703 (1951).

D6. A Collective Description of Nucleon Interactions. MELVIN FERENTZ AND DAVID PINES, *University of Pennsylvania*.—The behavior of an infinite nuclear medium, with a density equal to that of a real nucleus and with typical central exchange nuclear forces, is analyzed in terms of the nucleon spin and isotopic spin density fluctuations. Because of the high density and strength of interaction the system exhibits some collective behavior despite the short range of the nuclear interactions. A treatment similar to that used by Pines and Bohm[1] for dense electron gases is applied. We find that, under certain circumstances, the fluctuations in spin and isotopic spin density have an oscillatory behavior. An approximate dispersion relation for these oscillations is obtained. Within this approximation, one can express the Hamiltonian of the system as the sum of three terms, one of which involves only these oscillatory collective coordinates. The remaining terms represent the kinetic energy of the individual particles and the residual interparticle forces. An incident fast nucleon can lose energy in traversing the nuclear medium by exciting these oscillatory modes, and the energy lost in this manner per unit distance has been calculated. Further applications of this approach, and the extent to which it may be applied to real nuclei, will be discussed.

[1] D. Pines and D. Bohm, Phys. Rev. **85**, 338 (1952).

D7. (Abstract withdrawn.)

D8. Interaction Contributions to Magnetic Moments of Nuclei. L. Spruch and A. Russek, *New York University.*—An arbitrary linear combination of the three phenomenological interaction moment operators, which can arise from a charge exchange potential in a lowest order meson theory, is used. With few assumptions about the operator radial functions and the nuclear core, the interaction contribution in nuclear magnetons of an odd A nucleus with the odd nucleon in the state l, j can be written

$$M(\mathrm{int})=3I[-\epsilon\alpha\langle\sigma_z\rangle-(\beta/(2j+2))(\epsilon+4\langle\boldsymbol{\sigma}\cdot\mathbf{l}\rangle)+\gamma\langle l_z\rangle],$$

where $I(\text{odd } z)\approx(N/A)(a/r_0)^3$, $I(\text{odd } N)\approx-(z/A)(a/r_0)^3$ (crudely), ϵ is close to 4, a is the nuclear range, and $r_0=e^2/(2mc^2)$. The predictions that, for the same l and j, odd z nuclei give slightly larger contributions than odd N nuclei and that the addition of two nucleons of the "odd" type pushes the moment towards the Schmidt lines are in over-all agreement with the data. Actual calculations using the independent particle model give $I=.1$, $\epsilon=5$. $\alpha=2.3$, $\beta=-3.5$, and $\gamma=0.4$ then roughly match the data.

D9. On the Fermi-Thomas Model of the Nucleus. R. J. Riddell, Jr., *University of California, Berkeley.*—Qualitative arguments have indicated that the saturation phenomena of the nucleus could not be explained by the choice of a purely attractive potential of the Serber exchange type, although this is required to fit the high energy nucleon-nucleon scattering data. However, it was felt that a semiquantitative treatment of the nucleus by means of the Fermi-Thomas model perhaps would be worth while, and in addition might indicate what changes in the potential could be made to obtain agreement with experiment. By use of a Yukawa potential, which is particularly well adapted to the Fermi-Thomas model, it was found that all of the terms were of the same order for nucleon densities of interest, in opposition to the atomic case, in which the exchange terms are only a perturbation. An exact solution of the equation including these terms would be very difficult to obtain, and so to estimate the validity of the method a uniform density distribution was introduced. In this case, the stable nuclear radius was smaller than the range of the potential. An attempt to produce saturation by adding a repulsive core of shorter range will be discussed.

D10. The Scattering of Neutrons by Systems of Nuclei. Roy J. Glauber, *California Institute of Technology.*—In scattering by a bound aggregate of nuclei, a neutron interacts with the quantized vibrational modes of the system. A closed expression is derived for the differential scattering cross section in the presence of this interaction which is valid for all neutron energies and all vibrational temperatures of interest. This result agrees with and extends those already known in diverse energy and temperature limits. For scattering by crystals the expression for the cross section may be shown to sum the effects of the emission and absorption of arbitrary numbers of lattice quanta (phonons). In the transition to high energies the Laue spots become Gaussian in shape and increase in number and width—until in the limit in which interference effects are negligible, the scattering cross section approaches that of free nuclei with the correct reduced mass. The calculation has been based on some methods of treating processes involving a multiplicity of bose-particles,[1] which are here construed as excitation quanta. These methods are applicable as well to the treatment of electron and x-ray diffraction.

R. J. Glauber, Phys. Rev. 84, 395 (1951).

Thursday Morning at 10:30

NBS, East Building Lecture Room

(J. H. Van Vleck presiding)

Semiconductors

E1. On the Diffusion Theory of Noise in Rectifiers and Transistors. Richard L. Petritz, *Catholic University and U. S. Naval Ordnance Laboratory.*—Macfarlane[1] has recently proposed a diffusion theory of contact noise in semiconductors. We were making a similar investigation at the time that Macfarlane's paper appeared and had carried out the Fourier transform directly on the solution of the diffusion equation and then made the spacial integration obtaining expressions for the power spectrum for the one-, two-, and three-dimensional cases. There is a discrepancy between our result and Macfarlane's for the two-dimensional case which we have traced to an unfortunate misprint in Chandrasekhar's[2] paper. The correct expression for the correlation function is given in Smoluchowski's[3] paper. The power spectrum for all three cases approaches the $f^{-3/2}$ law at high frequencies. At low frequencies the one-, two-, and three-dimensional cases go as $f^{-1/2}$, $\log f$, and constant. We have applied the one-dimensional theory to the current noise resulting from ionic diffusion perpendicular to the plane of a metal-semiconductor contact and also in a $P-N$ junction and will report our results. A one-dimensional diffusion mechanism has some promise because of its slowly changing slope in the region of the turnover frequency.

[1] G. G. Macfarlane, Proc. Phys. Soc. (London) 63B, 807 (1950).
[2] S. Chandrasekhar Revs. Modern Phys. 15, 50 (1943), Eq. (391)
[3] M. V. Smoluchowski, Physik. Z. 17, 563 (1916), Eq. 17.

E2. Effects of Dislocations on Mobilities in Semiconductors.* F. Seitz and D. L. Dexter, *University of Illinois.*—The scattering of electrons or holes in semiconductors by the dilation of the lattice around rigid, randomly-arranged edge-type dislocations is treated by the method of the deformation potential.[1] The contribution of this scattering to the electrical resistance is determined from the Boltzmann transport equation by the method of Mackenzie and Sondheimer,[2] except for the use of Maxwell-Boltzmann, rather than Fermi-Dirac statistics. The temperature dependence of the reciprocal of the mobility μ is given by $1/\mu=\alpha_l T^{3/2}+\alpha_i T^{-3/2}+\alpha\, T^{-1}$, where the α's are temperature-independent quantities referring to scattering from the lattice, impurity atoms and dislocations, respectively. A discussion is given of the relative magnitudes of these three terms, and of the possibility of obtaining experimental information concerning dislocations in semiconductors by electrical measurements.

* Research supported by the ONR and AEC.
[1] J. Bardeen and W. Shockley, Phys. Rev. **80**, 72 (1950).
[2] J. K. Mackenzie and E. H. Sondheimer, Phys. Rev. **77**, 264 (1950).

E3. High Field Mobility in Germanium with Impurity Scattering Dominant. E. M. CONWELL AND E. J. RYDER, *Bell Telephone Laboratories.*—The variation of electron mobility with electric field has been observed in n type samples for which impurity scattering is dominant at low fields. Current measurements were taken using a pulse technique, with experimental precautions to keep the carrier density constant.[1] Since the mobility arising from impurity scattering is essentially proportional to v^3, it is expected that beyond the Ohm's law region mobility would increase rapidly with field until lattice scattering is dominant, causing a transition to the $E^{-\frac{1}{2}}$ dependence characteristic of that mechanism.[2] The data show this behavior. If the velocity distribution is assumed to be a δ-function, an approximate expression for mobility as a function of field can be obtained from the condition that average power loss must equal average power gain. As in the case of lattice scattering, the resulting theory fits the data well if the rate of energy loss is taken several times higher than that given by the usual theory.[2]

[1] E. J. Ryder and W. Shockley, Phys. Rev. **81**, 139 (1951).
[2] W. Shockley, Phys. Rev. **82**, 330 (1951).

E4. Lattice Defects in Germanium. W. C. DUNLAP, JR., *General Electric Research Laboratory.*—Evidence is reviewed for the hypothesis that the thermal conversion characteristics of germanium arise from the formation of lattice defects, which can act electrically as acceptors. These defects are presumed to be Frankel defects because of the conversion of high resistivity n-germanium to p-germanium resulting from a few seconds heating at 900°C. Studies have been made of the following types: (1) Samples quenched from high temperatures have been studied at liquid hydrogen temperatures. The activation energy for excitation of thermal acceptors is considerably greater than that for the ordinary chemical acceptors (0.03 compared to 0.003–0.006 ev). (2) Resistivity and Hall effect measurements have been made on single crystal samples of germanium quenched from various temperatures. The number of acceptors introduced appears to be roughly independent of the amount or the type of impurity already present. The activation energy for the formation of a defect is agout 1 ev. This value appears not inconsistent with the activation energy for diffusion, 2.5 ev, assuming a vacancy mechanism for diffusion.

E5. Growth of Silicon Single Crystals and of Single Crystal Silicon $p-n$ Junctions. G. K. TEAL AND E. BUEHLER, *Bell Telephone Laboratories.*—Single crystals of silicon having a high degree of lattice perfection and chemical purity have been produced by a technique similar to that reported for germanium.[1] This technique avoids strains and resultant cracks and twinning normally obtained on solidifying silicon within a container in the heretofore conventional manner and permits the preparation of crystals of controlled semiconducting properties. Single crystals 5 inches in length and 1-inch maximum diameter have been grown. Bulk lifetimes of carriers in these crystals may be made as high as 200 microseconds. Drift mobility of electrons in p-type crystals is 1200 cm^2/volt/sec, or four times as high as reported for previously available polycrystalline samples. The magnitude and type of conductivity in the direction of crystal growth is controlled by addition of a significant impurity such as boron (acceptor) or phosphorus or arsenic (donor) to the melt from which the crystal is being grown. Single crystal $p-n$ junctions have been made that show exceptionally low saturation currents that can be accounted for by the band separation in silicon and, moreover, give anomalous Zener characteristics, as discussed more fully elsewhere.[2]

[1] G. K. Teal and J. B. Little, Phys. Rev. **78**, 647 (1950).
[2] K. B. McAfee and G. L. Pearson, Bull. Am. Phys. Soc. **27**, No 2, 14(A) (1952).

E6. The Electrical Properties of Silicon $p-n$ Junctions Grown from the Melt. K. B. MCAFEE AND G. L. PEARSON, *Bell Telephone Laboratories.*—Silicon $p-n$ junctions have been grown from the melt[1] under accurately controlled impurity conditions. The saturation currents of such junctions ar room temperature are of the order of 10^{-7} amp/cm^2. At field strengths of approximately 2×10^5 volts/cm a very sharp increase in current is found. A change of voltage in this region of about one-half percent is sufficient to cause the current to change by two orders of magnitude. This measured field strength corresponds approximately to that predicted by the Zener-Shockley theory.[2] The measured slopes, however, differ from theory by a considerable factor. Experiment shows that the capacity of the junction biased in the direction producing space charge varies as the inverse cube root of the voltage thus indicating a linear change of impurities with distance. The above characteristics are of considerable practical importance in the construction of rectifiers, voltage regulators, voltage limiters, and other nonohmic devices. It should be pointed out that the noise level in the voltage regulating range s well above thermal.

[1] G. K. Teal and E. Buehler, Bull. Am. Phys. Soc. **27**, No. 2, 14 (1952).
[2] McAfee, Ryder, Shockley, and Sparks, Phys. Rev. **83**, 650 (1951).

E7. Silicon $p-n$ Junction Diodes Prepared by the Alloying Process. G. L. PEARSON AND P. W. FOY, *Bell Telephone Laboratories.*—$p-n$ junctions have been formed by alloying acceptor or donor impurities with n or p type silicon. The procedure is in contrast to diffusion techniques previously reported for germanium.[1] Aluminum is a very satisfactory acceptor impurity and gold-antimony alloy is a preferred donor impurity. The eutectic temperature for silicon-aluminum is 577°C and for silicon-gold 370°C. Single crystal[2] or multicrystalline silicon may be used although the former is preferred. The reverse saturation currents are smaller than those obtained in germanium of equal body resistance. For an area of 10^{-4} cm^2, values as low as 10^{-10} ampere have been obtained with a forward to back current ratio of 10^8 at 1 volt. The Zener current follows the law $I=KV^n$ over several decades of current with n as high as 1500 which is greater than theoretical.[3] The Zener voltage is proportional to the silicon resistance, and values between 5 and 1000 volts have been obtained for resistivities between 0.1 and 50 ohm cm. The above properties together with the ability to operate at elevated temperatures suggest several useful applications.

[1] R. N. Hall and W. C. Dunlap, Phys. Rev. **80**, 467 (1950).
[2] G. K. Teal and E. Buehler, Bull. Am. Phys. Soc. **27**, No. 1, 14 (1952).
[3] McAfee, Ryder, Shockley, and Sparks, Phys. Rev. **83**, 650 (1951).

E8. Effect of 11-Mev Electron Bombardment on the Electrical Properties of Germanium. LUTHER DAVIS, JR., G. A. DEMARS, L. G. RUBIN, AND J. H. SAUNDERS, *Raytheon Manufacturing Company.*—High and low resistivity samples of n and p type germanium were bombarded at room temperature at various exposures by 11-Mev electrons from the Massachusetts Institute of Technology linear accelerator. Use of such high energy electrons permits a homogeneous bombardment completely through the depth of the sample as well as a uniform bombardment of a considerable quantity of samples simultaneously. Moreover, the use of electrons minimizes the production of donor or acceptor centers from transmutations, permitting a quantitative study of the effects of lattice vacancies and interstitial Ge atoms. We have used $\Delta(n_e-n_h)$ for low resistivity n type material as a measure of the number of acceptors (n_A) formed by a given bombardment. For high resistivity (20 ohm cm) n- and p-type material, values of $\Delta(n_e - n_h)/n_A$ of the order of 0.06 were determined. Very little healing out was found by measurements at room temperature commencing one hour after bombardment and later. The theoretical cross section for electrons of this energy can be calculated knowing the threshold energy of about 0.6 Mev.[1] The value of n_A is about two orders of magnitude less than theoretical when measured.

[1] E. E. Klontz and K. Lark-Horovitz, Phys. Rev. **82**, 763 (1951).

E9. Electron Distribution in Irradiated *N* type Semiconductors. H. GLASER AND A. J. F. SIEGERT, *Northwestern University.*—We have calculated the electron distribution in a photoconducting plate infinite in extent in directions perpendicular to the incident light as a function of the distance from the irradiated surface assuming bimolecular recombination with traps. The nonlinear differential equations were solved aproximately by means of a variation principle. With reasonable estimates for the recombination probability and dielectric constant, our results are compatible with old measurements of the Dember effect.[1] Conversely, a measurement of the Dember effect and dielectric constant would permit a determination of the recombination probability using our calculations. The calculations are to be applied to a more detailed interpretation of the experiments of L. Gildart and A. W. Ewald.[2]

[1] H. Dember, Physik Z. **33**, 207 (1932).
[2] L. Gildart and A. W. Ewald, Phys. Rev. **83**, 359 (1951) and unpublished results.

THURSDAY AFTERNOON AT 2:15

NBS, East Building Lecture Room

(M. W. ZEMANSKY presiding)

Phosphors; Cryogenics

F1. Release of Trapped Charge in Alkali Halide Crystals. DAVID DUTTON, *University of Illinois.*—Crystals of KCl and KBr were irradiated with x-rays at liquid-nitrogen and liquid-helium temperatures and warmed to room temperature with an applied electric field. The release of trapped charge, associated with changes in the optical absorption of the crystals, has been observed. A preliminary report[1] described the appearance in KCl of free charge as the V_1 and F' bands[2,3] disappeared. This behavior is consistent with the model proposed by Seitz[4] for the V_1 center, namely, a positive hole trapped at a positive-ion vacancy. In KBr, release of trapped charge from V_1 and F' centers is also observed, as well as from several other trapping centers. Bursts of luminescence occur, correlated with changes in the absorption bands and the appearance of free charge. The spectral composition of the luminescent radiation has been studied by means of filters.

[1] Dutton, Maurer, and Heller, Phys. Rev. **84**, 363 (1951).
[2] Casler, Pringsheim, and Yuster, J. Chem. Phys. **18**, 887, 1564 (1950).
[3] H. Dorendorf, Z. Physik **129**, 317 (1951).
[4] F. Seitz, Phys. Rev. **79**, 903 (1950).

F2. Plastic Phosphors for Scintillation Counters. W. L. BUCK AND R. K. SWANK, *Argonne National Laboratory.*—Solid solutions (both simple and mixed) of various organic fluors in polystyrene are being studied for use as scintillation counter phosphors. Such phosphors containing tetraphenyl butadiene or terphenyl plus tetraphenyl butadiene have been made to give scintillation pulse heights up to 30 percent as large as those from a high quality anthracene crystal, using an RCA type 5819 photomultiplier with beta-particle excitation. It appears to be generally true that pulse height increases with increasing solute concentration over a wider range of concentrations than in the case of liquid solution phsophors, which indicates that the range of action of self-quenching is smaller in the case of the solid solutions. In many cases the maximum useful concentrations are determined by solubility, coloration, or by inhibition of polymerization. As is true with liquid solutions, the efficiencies obtained indicate that the scintillation process in these plastic phosphors is not confined solely to the dissolved fluor but involves a transfer of energy from the polystyrene to the dissolved fluor. Experiments will be described which shed light upon the nature of this process.

F3. (Abstract withdrawn.)

F4. Field Strength and Temperature Dependence of Electroluminescence in Powders. S. ROBERTS AND J. S. PRENER, *General Electric Research Laboratory.*—Electroluminescent cells are constructed by dispersing a copper activated zinc sulfo-selenide phosphor powder in a thermoplastic dielectric matrix. The resulting sheet material is observed to glow when an alternating electric field is applied. The light produced is not continuous, but flickers with twice the applied frequency, dropping to zero between flashes. The electric field in the phosphor particles can be calculated if they are assumed to be spheres; however, it is first necessary to determine their dielectric constant. This is done by comparing the dielectric constant of the phosphor-plastic aggregate with that of the clear plastic. The results of these calculations show that, for a variety of plastic matrix materials having different dielectric constants, the brightness of electroluminescence depends in the same manner on the electric field in the phosphor particles. A matrix of polystyrene was used in studying the brightness of electroluminescence *versus* temperature. This material has a relatively small temperature coefficient of dielectric constant. In this test only a small change of brightness was observed in a temperature range from −100°C to +50°C. This fact suggests that the mechanism responsible for electroluminescence may be akin to field emission.

F5. Temperature Dependence of Infrared Photoconductivity in Standard VII Phosphor. G. CONRAD AND J. J. DROPKIN, *Polytechnic Institute of Brooklyn.*—The dc infrared stimulated photoconduction of the Std VII phosphor (SrS:Ce:Sm) excited by 3650A at about 100°K, 200°K, and 300°K has been measured from 100° to 400°K. The photocurrent is strongly temperature dependent and suggests one or more thermal steps in the process. Peaks occur at low temperatures for the phosphor excited at 100°K. Semilog plots of the photocurrent *vs* $1/T$ show well-defined straight line portions. The activation energies associated with these are higher for the high temperature region and vary with the temperature of excitation, state of exhaustion, and intensity of infrared. The variation of slope is consistent with a single thermal step of the order of 0.1 ev, obeying a second-order rate process at low temperatures, and a first-order rate process at high temperatures. The dark current of the phosphor has been measured as a function of the temperature. Current "glow" peaks are found which are attributable to a system of shallow traps.

F6. Electron Traps in the KCl:Tl Phosphor. PETER D. JOHNSON AND FERD E. WILLIAMS, *General Electric Research Laboratory.*—The sites responsible for the principal thermoluminescent peaks[1] of KCl:Tl have been identified. Thermoluminescence has been measured at a linear heating rate of 0.083°K sec^{-1} from 20 to 400°K. Introduction of vacancies does not alter the two principal peaks, however Cd^{++} has a specific effect.[2] Infrared irradiation prior to warming suppresses them. The concentrations of trapped electrons have the same dependence on gross activator concentration as emission from isolated activators.[3] These facts in conjunction with theoretical considerations, indicate that the two principal traps are isolated Tl^+ in the $^3P_1$ and the $^3P_2{}^0$ states. The thermal trap depths of 0.38 and 0.72 ev permit the construction of a configuration coordinate diagram which adequately represents the role of the four lowest excited states of Tl^+ in the mechanism of luminescence of KCl:Tl. The frequency factors for untrapping are 10^8 sec^{-1}. The mechanism of filling the traps is deduced from the dependence on excitation temperature of the number of traps occupied.

[1] J. T. Randall and M. H. F. Wilkins, Proc. Roy. Soc. (London) **184A**' 382 (1945).
[2] P. D. Johnson and F. E. Williams, J. Chem. Phys. (to be published).
[3] P. D. Johnson and F. E. Williams, J. Chem. Phys. **18**, 1477 (1950).

F7. Change in Superconducting Penetration Depth with Field. J. BARDEEN, *University of Illinois.*—Pippard[1] observed that the relative change in penetration depth $\Delta\lambda/\lambda$ of tin between $H=0$ and $H=H_c$ is about 2.2 percent for $T<2.0$°K, decreases to a minimum at 3.1°K, and increases as $T\to T_c$. This suggests that two effects are operative, one at low and the other at high temperatures. Pippard attributes the change near $T=T_c$ to a decrease in the number of superconducting relative to normal electrons. This effect, largest at T_c, vanishes as $T\to 0$. According to the London approach, the usual penetration phenomena are associated with changes of the wave functions which are linear in H, giving an energy quadratic in H. It is suggested that $\Delta\lambda$ for low T results from changes in wave functions quadratic in H, giving an energy varying as H^4. Such terms yield $\Delta\lambda$ proportional to H^2. Because of the decrease in H_c, this contribution decreases as T increases. It is reasonable to expect that the combined effects will be a minimum near 3°K.

[1] A. B. Pippard, Proc. Roy. Soc. (London) **A203**, 210 (1950).

F8. Low Temperature Thermal Conductivity of Tin and Tin-Bismuth Alloys. D. P. DETWILER,* *Yale University.*†—The thermal conductivity of two tin-bismuth alloys containing respectively 0.134 percent and 1.02 percent bismuth has been measured in the normal and in the superconducting states in the temperature region from 1.3 to 4.2 degrees Kelvin. No evidence is found of the anomalous thermal conductivity in the superconducting state as reported by Mendelssohn and Olsen[1] in alloys of lead with comparable quantities of bismuth. Measurements on pure tin in a transverse magnetic field at temperatures below the superconducting transition temperature showed a definite minimum in the intermediate state region similar to that recently observed by Webber and Spohr[2] in pure lead. No such minimum was observed in the 0.134 percent bismuth alloy specimen. The conductivity measurements were made in the conventional manner, using carbon composition resistors as thermometers and a temperature gradient of approximately 0.02 degree per centimeter.

* AEC Pre-doctoral Fellow.
† Assisted by the ONR.
[1] K. Mendelssohn and J. L. Olsen, Phys. Rev. **80**, 859 (1950).
[2] R. T. Webber and D. A. Spohr, Phys. Rev. **84**, 384 (1951).

F9. Atomic Heat of Lead in the Neighborhood of its Transition to Superconductivity. J. R. CLEMENT AND E. H. QUINNELL, *Naval Research Laboratory.*—The atomic heat of lead in the normal and superconducting states was measured in the neighborhood of its transition to superconductivity. The data were generally in good agreement with previous measurements[1–3] but, due to increased precision, showed a discontinuity of about 4.5 percent at the transition temperature in zero applied magnetic field. The measured discontinuity is in good agreement with that which can be predicted from critical field values.[4,5]

[1] W. H. Keesom and D. H. Andrews, Proc. Amsterdam Acad. Sci. **30**, 434 (1927).
[2] W. H. Keesom and J. N. van den Ende, Proc. Amsterdam Acad. Sci. **33**, 243 (1930).
[3] W. H. Keesom and J. N. van den Ende, Proc. Amsterdam Acad. Sci. **34**, 210 (1931).
[4] J. G. Daunt and K. Mendelssohn, Proc. Roy. Soc. (London) **A160**, 127 (1937).
[5] Daunt, Horseman, and Mendelssohn, Phil. Mag. **27**, 754 (1939).

F10. Low Temperature Heat Capacity of Vanadium. R. D. WORLEY, M. W. ZEMANSKY,* AND H. A. BOORSE,† *Columbia University.*‡—The heat capacity of a 3.8-mole sample of vanadium has been measured in the normal and superconducting states. Data for the normal state were obtained over the temperature range 1.8° to 12°K, a magnetic field of about 5000 gauss being applied to keep the metal in the normal state at temperatures below the zero field transition. Data for the superconducting state were obtained from 1.8° to the zero field transition which was found to occur at 4.7°K. All temperatures were determined by means of a special carbon composition resistor calibrated and used according to the method described by Brown, Zemansky, and Boorse.[1] The molar heat capacities of the sample over the above noted range will be given, together with the value of γ, the coefficient of the linear term (electronic specific heat) in the normal heat capacity.

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

F11. On the Nuclear and Electronic Contributions to the Specific Heat of Neodymium Ethyl Sulfate Near 1°K. L. D. ROBERTS, C. C. SARTAIN,* AND B. BORIE, *Oak Ridge National Laboratory.*—The molar specific heat C_I of $Nd(EtSO_4)_3\cdot 9H_2O$ has been measured in the temperature range 0.95°K–2.15°K by the magnetic method of R. J. Benzie and A. H. Cooke at frequencies from 180 to 1200 cps. The measured C_I may be described within 1 percent by $C_I=b/T^2$ where T is the temperature and b is a constant. Three spherical, 1-cc, powder samples were measured. Sample I was prepared from neodymium of normal isotopic composition, and samples II and III were prepared from separated isotope samples of Nd^{142} and Nd^{143}. Using the measured b_I, b_{II}, and b_{III} in three simultaneous equations, one obtains the electron contribution to the specific heat b_{el}/T^2 and the hyperfine splitting contributions b_{143}/T^2 and b_{145}/T^2 with $b_{el}=0.147\pm0.004\times10^5$, $b_{143}=5.08\pm0.05\times10^5$, and $b_{145}=1.7\pm0.2\times10^5$ erg degree. These b_{143} and b_{145} agree within experimental error with the values 5.17×10^5 and 2.00×10^5 erg degree, respectively, computed from the microwave measurements of H. E. D. Scovil. Thus the hyperfine splitting contribution to the specific heat for $Nd^{143}(EtSO_4)_3\cdot9H_2O$ is some 30 times larger than the electron contribution which makes this material of interest in the study of nuclear effects below 1°K.

* Summer Research Participant from the University of Alabama.

F12. The Resistance Minimum in Magnesium at Low Low Temperatures.* H. E. RORSCHACH, JR., AND MELVIN A. HERLIN, *M.I.T.*—The electrical resistivities of three very pure magnesium samples from different sources have been measured from 1 to 40°K by an improved mutual inductance method.[1] All samples exhibit a minimum, although the effect is much more pronounced in one which is believed to contain more impurity than the others. Above 20°K, all of the resistivity curves can be well represented by a power law $\rho=\rho_r+aT^b$ with b equal to approximately 3.5. However, Matthiesen's rule does not hold, since at least two of the curves intersect.

* This work has been supported in part by the Signal Corps, the Air Materiel Command, and the ONR.
[1] H. E. Rorschach, Jr., and Melvin A Herlin, Phys. Rev. **81**, 467 (1951).

F13. Nonlinear Stationary Flow in Liquid Helium II.* P. R. ZILSEL AND H. M. FRIED, *University of Connecticut.*—The existence of a limiting velocity of superflow for internal convection through narrow slits in helium II is accounted for by equations of motion derived previously[1] when these are corrected to include the ordinary viscous friction of the normal fluid, without introducing Gorter's "internal friction."[2] The limiting condition is

$$v_s d<4\eta_n(\rho-\tfrac{1}{4}\rho_s)^{-1}\simeq5\times10^{-4}\text{ cm}^2/\text{sec},$$

(d = width of slit). When v_s exceeds the critical value, cubic terms in the equations of motion become important, accounting qualitatively for the observed cube-root dependence of heat conduction and fountain pressure on temperature gradient. Quantitative comparison between theory and experiment will be discussed.

* Supported by a grant from the Research Corporation.
[1] P. R. Zilsel, Phys. Rev. **79**, 309 (1950).
[2] C. J. Gorter, Physica **15**, 523 (1949).

THURSDAY AFTERNOON AT 2:15

Shoreham, Main Ballroom

(G. S. GOLDHABER presiding)

Apparatus of Nuclear Physics; Radioactive Nuclei

FA1. A Pair Spectrometer Using Four Scintillation Crystals.* R. S. FOOTE AND G. KAMM, *National Bureau of Standards.*—A pair spectrometer using four NaI(Tl) crystals has been developed to measure total pair electron energies produced by high energy x-rays. This spectrometer consists of the conventional three-crystal spectrometer[1] plus a large fourth crystal placed behind the central crystal of this three-crystal unit. This large crystal is used to detect escaping electrons and x-rays, and its circuitry is placed in anticoincidence with a coincidence pulse from the three-crystal spectrometer. The performances of the four-crystal and three-crystal spectrometers were compared by observing the gamma-ray spectrum emitted by $B^{11}(p,\gamma)C^{12}$ with a proton bombarding energy of about 180 kev. Spectra were taken independently and simultaneously to determine the spectrum of the events discarded by the fourth crystal. The resolution of these spectrometers as measured by the full widths of the lines at half-maximum was 6 percent for the 4.45-Mev line[2] and 13 percent for the 11.6-Mev line for the four-crystal unit, and 8 percent and 22 percent, respectively, for the three-crystal unit. The ratio of the energies of these two lines was determined to be 0.379 ± 3 percent. The energy calibration and resolution data are preliminary to the application of the spectrometer to betatron spectra determinations.

* This work was supported in part by the AEC.
[1] J. K. Bair and F. C. Maienshein, Rev. Sci. Instr. **22**, 343 (1951).
[2] T. Huus and R. B. Day, Phys. Rev. **85**, 761(A) (1952).

FA2. The "Impregnated" Scintillating Crystal as a Tool for the Study of Radioactive Decay. E. DER MATEOSIAN AND A. SMITH, *Brookhaven National Laboratory.**—When single crystals of sodium iodide activated with thallium are grown from a mixture of sodium and thallium iodides to which a minute trace of radioactive material has been added, the crystals show all the properties of normal scintillating crystals. In addition, the crystals will have dispersed through them the added radioactivity in a form which behaves effectively like a zero-thickness source. Previously, "impregnated" crystals have been used to study the total energy in isomeric transitions.[1] The method is now being adapted to study the following types of problems: (1) the detection of short-lived states following β-decay; (2) the detection of orbital electron capture and the determination of the ratio of orbital electron capture to β-decay; (3) the determination of β-spectra shapes and end points; (4) the efficient detection of soft particles and the ratio of L to K electron capture. Specific problems under investigation will be presented.

* Under contract with AEC.
[1] Scharff-Goldhaber, der Mateosian, Goldhaber, Johnson, and McKeown, Phys. Rev. **83**, 480 (1951).

FA3. Energy Response of Organic Liquid Scintillation Counters.* GEO. T. REYNOLDS, *Princeton University.*—The nonlinear energy response of organic scintillators to slow particles has been recognized for some time. By measuring the relative response of solutions of terphenyl in toluene to 5-Mev α-particles and 624-kev electrons as a function of terphenyl concentration, it is possible to differentiate to some extent among the possible causes of this response. Such measurements have shown, for example, that the relative probability of self-quenching in the solvent to energy transfer is greater in the α-particle case than in the electron case. The discussion will be extended to discuss several mechanisms that can account for the nonlinear response without requiring dissociation of the solvent molecules.

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

FA4. Determination of the Resolving Time of Coincidences. Z. BAY, *The George Washington University*.*—To avoid ambiguity one should distinguish between two resolving times. The first (τ) is related to coinciding pulses and will be defined as one-half of the ratio of the area of the delay curve to the total number of coincidences per second. τ determines the number of chance coincidences and physically it means the average time within which a pulse gives a coincidence with another. This is a generalization of the original definition of the resolving time. By the differential coincidence counting method, τ can be improved far below the pulse period; because there is no loss of efficiency the total number of coincidences, and hence τ, can be determined. The second resolving time (τ') is usually defined as the half-width (or better, one-half the ratio of the area to the maximum) of the delay curve for simultaneous events. $\tau' \geq \tau$, because τ' includes time lags of detectors and of the equipment; their mean square deviations are additive terms in the second moment of the delay curve. Our recent results using scintillation counters are 1×10^{-10} sec for τ and 8×10^{-10} sec for τ'. Since τ gives the length of independent time intervals of the delay curve, it should be called the true resolving time and τ' the practical resolving time.

* Supported by the ONR and AEC.

FA5. Limitation of Discharge in G-M Counters,* W. C. PORTER AND W. E. RAMSEY (*Introduced* by W. F. G. Swann). —Three of the four serious limitations involved in G-M counters rise out of the part of the discharge which is unused. It has been possible by employing a simple two-tube feedback arrangement to limit the discharge in a counter to a small segment of its length, subsequently restoring all but a small portion of the tube to full sensitivity in about one microsecond. This procedure results in a marked reduction in deadtime, a correspondingly large increase in life, and an associated reduction in spurious counts. For instance, a 20-cm counter may be operated at a rate of 20,000 counts per second with a loss of no greater than that normally encountered at 1000 counts per second. Counting rate data will be given along with studies of the discharge distribution with and without the cut-off procedure. Alteration in the dead-time picture will be illustrated by oscillograms.

* Assisted by joint programs of the ONR and AEC.

FA6. Automatic Scanner for Multichannel Pulse-Height Analysis of 35-mm Film Record. D. J. ZAFFARANO AND WARREN A. HUNT, *Iowa State College*.—Spectra of short-lived nuclides have previously been obtained by photographing pulses displayed on an oscilloscope screen with a 35-mm moving film camera, and visually analyzing the film. The pulses from a scintillation spectrometer were intensified at their peaks to produce "dots" on a cathode-ray tube screen whose displacement from a baseline was proportional to the input pulse amplitude. An automatic device has now been built which will accurately scan these film records and print the total counts in each channel. The channel width may be varied, but at a given setting, the channel width and uniformity are held to less than 1 percent. The channel position is accurate to ±1 percent of the average pulse amplitude. Practically all of this position instability results from "wobble" of the film in the gate of the camera used, and is believed remediable to some extent. Within 3 inches deflection on an oscilloscope tube, at least 45 channels can be obtained. A spectrum of 100,000 events is obtainable from an exposure of 100 feet of film. The disadvantage of the present system is that several hours must elapse before the results of an experiment are known. Where this is tolerable, the method described here has the advantage that almost any pulse spectrum which can be observed with an oscilloscope can be determined quantitatively.

FA7. Electron Paths in a Magnetic Lens Spectrometer. W. S. EMMERICH, Y. NOGAMI, L. A. KILEY, AND J. D. KURBATOV, *Ohio State University*.—Baffle systems for a magnetic lens spectrometer have been designed making use of a graphical method to determine approximately the electron paths in inhomogeneous magnetic fields. From a set of graphs which give an approximation of the projection of an electron path in the plane perpendicular to the central axis of the spectrometer, sufficient information is derived to construct a baffle system. Conversion electrons of the 134-kev transition in Pr 144 were measured, in a system built according to this method, with a resolution of four percent and a transmission of about three percent. Another baffle system, designed for higher energies, resolved the conversion electrons of the 662 kev transition in Ba 137 requiring a power of 175 watts. A comparison of these experimental results with the corresponding values obtained by computation using the graphical method will be presented.

FA8. Pair Measurement of Gamma-Rays with a Lens Spectrometer. DAVID E. ALBURGER, *Brookhaven National Laboratory*.*—A conventional lens spectrometer has been adapted to the measurement of high energy gamma-rays by detecting positron-electron pairs in coincidence. The source and converter are centered on the optic axis and the baffle system selects pairs of nearly equal energy. The detection method consists of dividing the focal circle of confusion in half and observing coincidences between particles entering these two regions. Statistically the components strike different areas in half the cases. The detectors are semicircular anthracene crystals connected by light pipes to 1P21 photomultiplier tubes. Pulses from these are fed through amplifiers to a coincidence circuit of 7×10^{-8} sec resolving time. The method has been tested by observing "pair peaks" due to the 2.76- and 2.62-Mev gamma-rays of Na^{24} and ThC″, respectively. The Po−Be reaction gamma-ray has been measured at 7.5 percent resolution and found to have an energy of 4.47 ± 0.04 Mev. By using a proton beam from the Brookhaven electrostatic accelerator, gamma-rays of 6.19 ± 0.08 Mev and 7.13 ± 0.12 Mev occurring in the $F^{19}(p\alpha)O^{16}$ reaction have been observed with this apparatus.

* Under contract with the AEC.

FA9. An Experimental Effort to Detect Double Beta-Decay in Sn^{124} and Zr^{96}. J. A. MCCARTHY, *University of Rochester*.—If double beta-decay occurs without the emission of neutrinos, the total kinetic energy of the two emitted electrons will be constant. An experiment which takes advantage of this fact has been performed. The sample to be investigated is placed between two stilbene crystals observed by separate photomultipliers. Simultaneous current pulses from these photomultipliers are added electronically and analyzed by a thirty-channel pulse-height discriminator. Recording occurs only when there is a coincidence between pulses from the two photomultipliers. The background is reduced by an anticoincidence arrangement of four large guard crystals. The crystals are surrounded by four inches of lead. The background counting rate is 6.7 counts per hour in the energy region from 1 to 4 Mev. Preliminary data set a lower limit on the lifetime of Sn^{124} for double beta-decay at 1×10^{17} years on the assumption of a disintegration energy between 1 and 1.75 Mev, and 2×10^{17} years on the assumption of an energy between 1.75 and 3.2 Mev. Results for Zr^{96} will also be presented.

FA10. Internal Conversion Electron Ratios in Ba^{137m}, Sr^{87m}, Y^{89m}, and Zr^{89m}.* W. L. BENDEL, F. J. SHORE, H. N. BROWN, AND R. A. BECKER, *University of Illinois.*—Conversion electron ratios were measured with a double-focusing magnetic spectrometer employing resolution in the range 0.26 percent to 1.9 percent. The Ba^{137m} gamma-ray at 661 kev was found to yield a $K:L:(M+N)$ ratio of 5.5:1:0.27. The Sr^{87m} gamma-ray at 388 kev yielded 5.5 for $K/L+M$. The 4.4-minute Zr^{89m} transition at 586 kev gave 5.4 for $K/L+M$, and the 910-kev gamma-ray in Y^{89m}, following the decay of 79-hour Zr^{89}, yielded a $K/L+M$ ratio of 7.0. The Cs^{137} (obtained from Oak Ridge) was deposited on 0.0001-inch copper foil. The Zr and Y activities were in the form of 0.0005-inch zirconium foil. The strontium, in hydroxide form, was deposited on 0.00025-inch copper foil. The active Zr^{89m}, Y^{89m}, and Sr^{87m} were produced by gamma-n processes employing the betatron probe technique. All these transitions have been designated previously as being of the M-4 type.[1,2]

* Supported in part by the joint program of the AEC and ONR.
[1] Shore, Bendel, and Becker, Phys. Rev. **83**, 688 (1951).
[2] M. Goldhaber and A. W. Sunyar, Phys. Rev. **83**, 906 (1951).

FA11. The Radioactivity of Argon 39. C. E. ANDERSON, G. W. WHEELER, AND W. W. WATSON, *Yale University.**—The $A^{38}(d, p)A^{39}$ reaction has been investigated using samples of argon gas enriched by the thermal diffusion method to about 2 percent and with the ratio A^{36}/A^{38} about 2 to 1. A^{39} proton groups are observed at about 100 cm range, using 3.8-Mev deuterons. The short-lived β-activity of A^{39} previously reported[1] seems not to exist. A sample of argon enriched to 2 percent A^{38}, 6 percent A^{40} was irradiated in the Brookhaven reactor for 30 days in order to study the long-lived activity.[2] We find that this gas does have a long-lived beta- and also low energy gamma-radiation.

* Assisted by the AEC.
[1] A. Zucker and W. W. Watson, Phys. Rev. **80**, 966 (1950).
[2] Brosi, Zeldes, and Ketelle, Phys. Rev. **79**, 902 (1950).

FA12. The Gamma-Radiations from V^{48} and Nb^{92}. DAVID GREEN, HAROLD K. TICHO, AND J. REGINALD RICHARDSON, *University of California at Los Angeles.*—The isotope V^{48} was prepared by a (p, n) reaction on titanium and subsequent chemical extraction of the vanadium fraction; the γ-rays following the disintegration of V^{48} were analyzed on a scintillation γ-ray spectrometer. Aside from the well-known γ-rays at 0.99 and 1.32 Mev, a high energy γ-ray at 2.22 ± 0.02 Mev was observed. Clearly this γ-ray cannot be a cross-over line which would involve the sum of the two above-mentioned γ-rays. The intensity of the high energy γ-ray relative to the 1.32 Mev γ-ray is about 3.5 percent; this intensity ratio was followed over several half-lives. A search was made for a 90-kev γ-ray which might be in cascade with the 2.22-Mev line, but without success. The isotope Nb^{93} was prepared by a (p, pn) reaction on niobium, and a chemical separation of niobium. Gamma-rays at 0.933 ± 0.009 Mev and 1.84 ± 0.02 Mev were observed. The 0.933-Mev activity decayed with the 10-day half-life of Nb^{92}, but the half-life of the 1.84-Mev activity was much longer and should probably be assigned to an isomeric state of Nb^{93}. During long background runs, a γ-ray at 1.45 Mev appeared consistently. This γ-ray has been identified as due to K^{40}.

THURSDAY AFTERNOON AT 2:15

Shoreham, West Ballroom

(W. R. BRODE presiding)

Symposium on Chemical Physics

G1. Significance of the Results of Microwave Spectroscopy for Chemical Valence Theory. E. BRIGHT WILSON, *Harvard University.* (45 min.)

G2. The Theory of Transport Phenomena in Polyatomic Gases. G. E. UHLENBECK AND C. S. WANG CHANG, *University of Michigan.* (45 min.)

G3. Ionization and Dissociation of Diatomic Molecules by Electron Impact. H. D. HAGSTRUM, *Bell Telephone Laboratories.* (30 min.)

G4. Contributions of Electron-Impact Studies to Our Knowledge of Molecular Energies. D. P. STEVENSON, *Shell Development Company.* (30 min.)

THURSDAY AFTERNOON AT 2:15

Wardman Park, Continental Room

(L. J. HAWORTH presiding)

Invited Paper

H1. Photodisintegration of the Deuteron at High Energies. A. C. HELMHOLZ, *University of California, Berkeley.* (40 min.)

Photonuclear Reactions

H2. Photodisintegration of Deuterium at 180–260 Mev.* RAPHAEL LITTAUER AND JAMES KECK, *Cornell University.*—Equivalent targets of D_2O and H_2O are irradiated with bremsstrahlung from the Cornell 315-Mev electron synchrotron. Protons emitted at a given laboratory angle are counted in a coincidence-anticoincidence telescope, which defines a given range interval for charged particles and identifies them by their specific ionization. The only process in deuterium which can give rise to protons in the range of angles and energies investigated is photodisintegration. No proton production is possible from hydrogen over this range. The energy of the proton determines the energy of the photon responsible for the disintegration, so that we are able to measure the cross section of the reaction as a function of photon energy and of proton angle. Preliminary results indicate that the differential cross section at 90° in the laboratory system is of the order of 4×10^{-30} cm^2 sterad^{-1}, and that it does not vary steeply with energy over the range 180–260 Mev. Our result is in good agreement with that obtained by Benedict and Woodward[1] at 160-Mev photon energy.

* Work supported by the ONR.
[1] T. S. Benedict and W. M. Woodward, Bull. Am. Phys. Soc. 27, No. 1, 54 (1952).

H3. Investigation of the Reaction $C^{12}+h\nu=3\ He^4$ with γ-Rays up to 48 Mev.* V. L. TELEGDI, *University of Chicago*.—Nuclear emulsions of 400μ-thickness (to minimize loss of high energy events) were exposed to bremsstrahlung from the Chicago betatron. Previous work[1] on the energy dependence and the mechanism of the photodisintegration of C^{12} into three alphas was thus extended up to 48 Mev. From the energy distribution of the stars and a thin-target spectrum $\sigma(h\nu)$ is obtained. The cross section goes after the well-known[2,3] peak at $\sim$18 Mev through another maximum of roughly 4 Mev half-width, centered around 29 Mev. Out of 250 events, only three are caused by quanta of more than 35 Mev. Both peaks are within 20 percent of the same height (0.2 mb). The events induced by quanta larger than 24.3 Mev appear to go predominantly via an excited state of Be^8 at approximately 17 Mev and of 1 Mev (experimental) width, in satisfactory agreement with the work of Wilkins and Goward.[4] Theoretical considerations on the properties of this level will be presented.

* Work partly supported by joint program of the AEC and ONR.
[1] M. Eder and V. L. Telegdi, Helv. Phys. Acta. 25, 55 (1952).
[2] Goward, Telegdi and Wilkins, Proc. Phys. Soc. (London) A63, 402 (1950).
[3] F. K. Goward and J. J. Wilkins, Proc. Phys. Soc. (London) A64, 201 (1951).
[4] J. J. Wilkins and F. K. Goward, Proc. Phys. Soc. (London) A64, 1056 (1951).

H4. Fine Structure in the $O^{16}(\gamma, n)O^{15}$ Activation Curve. R. N. H. HASLAM, L. KATZ, R. J. HORSLEY, A. G. W. CAMERON, AND R. MONTALBETTI, *University of Saskatchewan*.—The energy of the University of Saskatchewan betatron has been found generally to be stable to within 30 kev. Under favorable conditions, the stability is much better. During an investigation of the $O^{16}(\gamma, n)O^{15}$ reaction in the vicinity of the threshold under particularly stable conditions, the activation curve was found to consist of a number of short straight line portions. The discontinuities in this curve are attributed to the effect of photonuclear absorption by individual levels in O^{16}. Preliminary values of the energies of these levels are 15.60, 15.84, 16.56, 16.72, and 16.96 Mev. The first level occurs near the threshold to be expected from mass differences,[1] and at a considerably lower value than obtained in previous threshold measurements.[2]

[1] Li, Whaling, Fowler, and Lauritsen, Phys. Rev. 83, 512 (1951).
[2] G. C. Baldwin and H. W. Koch, Phys. Rev. 63, 59(A) (1943); 67, 1 (1945).

H5. Photonuclear Yields from Copper Through Arsenic.* R. J. DEBS, J. T. EISINGER, A. W. FAIRHALL, I. HALPERN, AND H. G. RICHTER, *M.I.T.*—The 330-Mev x-ray beam of the Massachusetts Institute of Technology synchrotron is being used in a survey of photonuclear reactions induced in a group of nuclides between copper and arsenic. Radioactive products have been chemically separated from the targets, counted on standardized Geiger counters, and the resulting decay curves have been analyzed. The relative (γ, n), (γ, p), (γ, np), and $(\gamma, 2n)$ yields are in good agreement with earlier experiments.[1] The γ, pn (probably γ, d) yields from Zn^{64} and Ge^{70} comprise 18 and 5 percent, respectively, of the corresponding γ, n yields. For a given element, the γ, pn yields are highest for the lighter isotopes. γ, α yields run about 1 percent of γ, n yields and reactions involving the emission of two α's are down in intensity from γ, n reactions by a factor of 10^3 to 10^4. When α's are emitted, they tend to be accompanied by a few neutrons; for example, the ratios to the γ, n yield of the yields corresponding to $(\gamma, 2\alpha)$, $(\gamma, 2\alpha 3n)$ and $(\gamma, 2\alpha 6n)$ reactions on As^{75} are 2, 18, and 5, $\times10^{-4}$, respectively. Some of the activities corresponding to the emission of many nucleons are perhaps associated with meson production. In all the nuclides examined, the γ, n yield exceeds the sum of all the other yields.

* This work was supported in part by the joint program of the ONR and AEC.
[1] Karl Strauch, Phys. Rev. 81, 973 (1951).

H6. The Photoneutron Cross Sections for the Reactions $Br^{81}(\gamma, n)Br^{80}$ and $Br^{81}(\gamma, n)Br^{80*}$ and an Analysis of the Ratio Between These Cross Sections. L. KATZ, L. PEASE, AND H. MOODY, *University of Saskatchewan*.—Cross-section curves have been measured as a function of energy for the reactions $Br^{81}(\gamma, n)Br^{80}$ and $Br^{81}(\gamma, n)Br^{80*}$ and the ratio between these cross sections has been examined critically. The curves exhibit the peaked shape characteristic of photonuclear reactions with maximum cross sections of 88 and 42 millibarns, respectively. It is shown that the ratio of the cross sections depends on the spins of the excited levels in which the Br^{80} nucleus is left prior to γ-cascading and thus on the reaction leading to it. An elementary analysis based on this point of view gives results consistent with the ratio measured for six different types of reactions.

H7. Neutron Production by High Energy Quanta. K. M. TERWILLIGER AND L. W. JONES, *University of California, Berkeley*.—Total neutron yields from 12 elements were obtained as a function of the maximum beam energy of the 320-Mev Berkeley synchrotron. Points were obtained at 40-Mev intervals from 40 to 320 Mev by cutting off the rf at the appropriate fraction of peak field. The neutrons were detected at 90° to the beam axis with a BF_3 long counter. The diffusion time of the neutrons and the 0.5 μsec resolving time of the counter allowed high counting rates with the 20 μsec beam pulse. The yields at the different energies were normalized to the β^+ activity of Cu^{62} produced from the reaction $Cu^{63}(\gamma, n)Cu^{62}$. This normalization agreed with that made by total neutron yields from deuterium. Both methods are presumed sensitive only to quanta of less than 40 Mev. The normalized total neutron yields from the 12 elements increased with maximum beam energy from 40 to 320 Mev, the 40-Mev yields being about 60 percent of the 320-Mev yields. Using the photon difference method, cross sections for neutron production were estimated as a function of energy.

H8. A Method for Determining Cross Sections from Photonuclear Yield Curves. L. V. SPENCER, *National Bureau of Standards*.—Various methods have been used to obtain cross sections from photonuclear yield curves. They rely either on an extremely crude approximation to the thin target bremsstrahlung spectrum[1] or on a triangular system of linear equations[2,3] which seems basically unstable, so that the cross sections so determined become progressively less reliable at higher energies. A method for analyzing yield curves will be presented which uses bremsstrahlung spectra of any available accuracy. This method has proved convenient and accurate. The bremsstrahlung spectrum is represented as a rapidly converging sequence of terms which are essentially functions of the fraction of energy radiated. The formula for the yield curve is represented as a "folding" of the bremsstrahlung spectrum over the cross section. The cross section is determined by "folding back" the bremsstrahlung spectrum by means of an inverse operator and then differentiating in the manner of reference 1.

[1] G. C. Baldwin and G. S. Klaiber, Phys. Rev. **80**, 407 (1948).
[2] Johns, Katz, Douglas, and Haslam, Phys. Rev. **80**, 1062 (1950).
[3] L. Katz and A. G. W. Cameron, Can. J. Phys. **29**, 518 (1951).

H9. Analysis of Some Photoneutron and Photoproton Experiments. ARTHUR PASKIN, *Iowa State College.*—Hirzel and Wäffler[1] performed several experiments to determine the relative proton and neutron yield from photoreactions on the middle-weight elements. They found an excess of photoprotons over that computed on the basis of the statistical theory of nuclear reactions.[2] However, it is now found that their data are in agreement with the statistical theory if proper emission thresholds are used. Hirzel and Wäffler counted the photoprotons and neutrons from different nuclides. They made their comparisons as if their data were obtained from the same nuclide. This implied higher proton thresholds than neutron thresholds. Data available from current literature show that the particular proton thresholds in question are lower than their respective neutron thresholds.

[1] Hirzel and Wäffler, Helv. Phys. Acta **20**, 373 (1947); Wäffler and Hirzel, Helv. Phys. Acta **21**, 200 (1948).
[2] Weisskopf and Ewing, Phys. Rev. **57**, 472 (1940).

H10. Angular Distribution of Neutrons Exceeding 50 Mev Ejected by 320-Mev Bremsstrahlung.* D. W. KERST, L. J. KOESTER, A. S. PENFOLD, AND J. H. SMITH, *University of Illinois.*—A preliminary experiment has been performed on the angular distribution of neutrons produced in a carbon target by x-rays from the 320-Mev betatron. The neutrons produced recoil protons in a paraffin converter. Protons more energetic than 50 Mev were counted in a stilbene coincidence telescope. Thick lead shielding and an anticoincidence crystal preceded the paraffin converter and prevented charged particles from counting. The neutron angular distribution shows yields relative to a maximum at 45° of: 30°, 0.85; 45°, 1.00; 60°, 0.85; 80°, 0.69; 100°, 0.37; 120°, 0.35. The process described by Levinger[1] would give a maximum at a larger angle. Yields as a function of betatron energy indicate that a considerable fraction of these neutrons are produced by photons above 250 Mev. Nuclear emulsions exposed at the position of the proton telescope showed that no mesons were present. Other tests showed that electrons and secondary neutrons were not counted. Some measurements were also made with paraffin, aluminum, and copper targets.

* Supported in part by the joint program of the AEC and ONR.
[1] J. S. Levinger, Phys. Rev. **84**, 43 (1951).

THURSDAY AFTERNOON AT 2:15

Wardman Park, Burgundy Room

(H. P. ROBERTSON presiding)

Theoretical Physics, Including Relativity

I1. The List of Physical Dimensions. JOHN Q. STEWART, *Princeton University.*—P. W. Bridgman's authoritative treatise on dimensional analysis does not discuss how many dimensions exist because this is irrelevant for that class of problems. He shows indeed that their solution becomes better determined if a situation permits appending to the tally of primary dimensions one or more extra quantities not dimensionally independent. For describing classical physics as a model for other sciences, the question, "How many independent dimensions?" becomes significant. We suggest six in the current state of physical knowledge (although in a conference discussing physics as a model for social physics Bridgman and Duane Roller thought no definite count could be made). Particular sets of six have particular advantages: choice of energy, momentum, distance, and electrical charge exhibits the symmetry of mechanics with electrodynamics and also avoids all fractional exponents for derived quantities (as pointed out by J. W. Stewart). One additional dimension is needed for heat, and a sixth for chemical equations, for example, temperature and Avogadro's number. The last obviously involves arbitrary choice of a unit of measurement, the mole, not determined by the other five. Necessity of such new arbitrary choice, to avoid expressing measurements of different things in the same unit, is the defining characteristic of a dimension.

I2. Conformal Invariance in Special Relativity. WESLEY E. BRITTIN, *University of Colorado.*—If we restrict ourselves to the use of conformal coordinate transformations, the metric of the special theory of relativity is always of the form[1] $ds^2=\lambda^2 d\sigma^2$, where $d\sigma^2=n_{ij}dx^idx^j$ and n_{ij} is given by $||n_{ij}|| = ||n^{ij}|| = ||^1 -1_{-1_{-1}}||$. By use of this metric we may use the formalism of Riemannian geometry to investigate the conformal invariance of various equations. n_{ij} and n^{ij} are numerical tensors of weights $-\frac{1}{2}$ and $+\frac{1}{2}$, respectively, which are used to raise and lower indices of weighted tensors. It is shown that the only conformally invariant scalar meson wave function has a weight of $\frac{1}{4}$. Maxwells' equations, as is known, are conformally invariant, but the Lorentz condition on the electromagnetic potentials is not. There is no conformally invariant vector wave equation of the type $\Box\varphi^u+m^2\varphi^u=0$, where $\Box\equiv n^{ij}(\partial/\partial x^i)(\partial/\partial x^j)$. Other equations will be discussed.

[1] E. L. Hill, Phys. Rev. **72**, 143 (1947).

I3. Relativistic Statistical Thermodynamics. A. E. SCHEIDEGGER AND R. V. KROTKOV, *Queen's University.*—Bergmann[1] has generalized Gibbs' classical statistical mechanics so as to make it applicable to both relativistic and quantum-mechanical systems. His method, however, involves some complicated differential geometry, and the resulting formulas are not easily manageable. A different method for obtaining a relativistic and quantized statistical thermodynamics is proposed which avoids the differential geometry and gives simpler final formulas. The end results agree with the usual phenomenological relativistic thermodynamics, in which the entropy is a relativistic invariant, while heat and inverse temperature are generalized to be quadrivectors.

The new method is essentially to replace the Hamiltonian operator appearing in ordinary quantum statistics by a quadrivector, the energy-momentum operator $\mathbf{P}$. The relativistic canonical ensemble is then defined by the density operator $\mathbf{U}=\text{const}\exp(-\boldsymbol{\vartheta}\mathbf{P})$, which is Lorentz invariant, for the inner product $\boldsymbol{\vartheta}\mathbf{P}$ is $k\boldsymbol{\vartheta}$ (k = Boltzmann's constant) is then a quadrivector of inverse temperature, while the entropy S, defined as $S=\text{const trace }(\mathbf{U}\ln\mathbf{U})$, is clearly invariant, since $\mathbf{U}$ is. Heat may also be defined, in a way closely analogous to that used in the classical case, as a quadrivector $\boldsymbol{\delta}\mathbf{Q}$ satisfying the relativistic second law $k\boldsymbol{\vartheta}\boldsymbol{\delta}\mathbf{Q}=dS$.

[1] P. G. Bergmann, Phys. Rev. **84**, 1026 (1951).

I4. A New Approximation for the Gravitational Field Equations.* JOSHUA GOLDBERG AND PETER G. BERGMANN, *Syracuse University*.—In the approximation method introduced by Einstein and Infeld, the velocities of the particles are assumed to be small compared with the velocity of light.[1] However, the restriction to slow motion rules out the investigation of possible gravitational radiation. If this restriction is dropped, one has difficulty integrating the field equations beyond the first order, as the higher orders require advance knowledge of the particle's motion. In order to bypass this difficulty we propose to investigate the field equations in the Hamiltonian formalism. This approach has the advantage that all the field equations are solved with respect to the highest time derivatives—the first—and that, therefore, solutions of the canonical field equations can be built up as Taylor expansions in time. Once we have chosen initial values for the field variables consistent with the primary and secondary constraints, the problem of investigating the motion and radiation of the particles is reduced to the evaluation of certain surface integrals.[2]

* Supported by ONR.
[1] A. Einstein and L. Infeld, Can. J. Math. 1, 209 (1949).
[2] J. Goldberg and R. Schiller, Bull. Am. Phys. Soc. 27, 45 (1952).

I5. The Structure of the Canonical Coordinate Transformation Group.* PETER G. BERGMANN AND RALPH SCHILLER, *Syracuse University*.—In a variational principle of ordinary mechanics, time and the (negative) energy can be converted formally into dynamical variables in an expanded phase space of $(2f+2)$ dimensions. The group of canonical transformations in that expanded space includes coordinate-dependent changes in the time scale. In a field theory, a similar formalism can be developed by the introduction of so-called parameters. The introduction of the first three parameters (u^s) creates no problems but causes the first three x^s and their conjugate (linear momentum) densities to become canonical variables. However, the replacement of x^4 by a new parameter (t) gives rise to the equivalent of infinitely many new dynamical variables $x^4(u^s)$ and is, therefore, not quite equivalent to the introduction of a parameter in mechanics. Coordinate transformations involving all four coordinates can be represented by canonical transformations and by a generating functional. Parameter transformations, if they involve t, may either be represented merely by a new choice of initial conditions, without a canonical transformation, or by a new choice of hyper-surface system in function space, combined with a canonical mapping. In the quantized theory, these troublesome parameter transformations do not occur.

* Supported by ONR.

I6. Canonical Coordinate Transformations and Constraints in Nonlinear Theories.* RALPH SCHILLER AND PETER G. BERGMANN, *Syracuse University*.—In Lorentz-covariant field theories, the infinitesimal variations of the four-dimensional action integral depend only upon a functional over a three-dimensional hypersurface of space-time, when the field equations are satisfied. However, in theories whose field equations are covariant under arbitrary coordinate transformations, the variation of the action integral can be shown to vanish identically under a variation generated by an infinitesimal coordinate transformation. First the variation is equal to a vanishing total divergence integrated over four-space. The fourth component of the pseudo-vector whose divergence vanishes is then shown to be a constant of the motion when integrated over a spatial domain. This integrated fourth component of the pseudo-vector becomes our generating functional when we pass over to the Hamiltonian form of the theory and assume that the field equations are satisfied.[1] It then generates the infinitesimal coordinate transformations of all the canonical field variables. The generating functional can be utilized to find the explicit form of the primary and secondary constraints of covariant theories and the equations of motion of singularities as well.

* Supported by ONR.
[1] Rosenfeld, Ann. Physik 5, 113 (1930).

I7. A Possible Solution of the Clock Paradox. RICHARD SCHLEGEL, *Michigan State College*.—The gravitational field treatment of the clock paradox* has been widely regarded as not giving a satisfactory solution. In nature the Lorentz time transformation is exemplified by particle and photon waves, since that transformation gives the space-time relations for both deBroglie and electromagnetic waves. No paradox results from observation of such waves because the periodic "wave" oscillations possess no aperiodic feature. (A proper clock must have a noncyclic characteristic as well as uniformly recurring cycles.) The relativistic clock paradox may be avoided, then, by restricting the Lorentz equation, $t'=(t-xv/c^2)/(1-v^2/c^2)^{\frac{1}{2}}$, to "Lorentz processes" which result from inter-relatedness of space and time. The equation would then not be valid for "Clausius processes," that is, for clocks or processes generally for which an entropy may be defined. This proposed restriction is in accord with the customary result that the entropy of a system is Lorentz invariant and justifies the assumption of a common time in cosmological models. The constance of c is assured by applying the Lorentz transformations to the space and time intervals of electromagnetic waves rather than to entropy clocks. Ives' experiments and meson decay measurements will be discussed.

* R. C. Tolman, *Relativity, Thermodynamics, and Cosmology* (Oxford University Press, London, 1934), pp. 194–198.

I8. On Darling's Theory of the Elementary Particles and Born's Reciprocity Hypothesis. HANS FREISTADT, *Dublin Institute for Advanced Studies*.*—The operator $f\equiv 2J_1(z)/z$, which appears in Darling's "Theory of the Elementary Particles"[1] is a solution[2] of $(\partial^2/\partial z_s^2+1)f=0$, an equation formally analogous to the Klein-Gordon equation, of which it is the counterpart in Born's reciprocity theory.[3] In line with Born's ideas, we would expect solutions of this equation to have some significance in the theory of elementary particles. The mass spectra proposed by Darling[1] and Zilsel[4] are slightly modified, so as to include neutral particles. If the masses of the electron, π^0, π^+, and proton are used to adjust parameters, the spectrum contains masses that might be identified with the neutrino, μ^+, τ^+,[5] V_1^0, and V_2^0.[6] The mass of the neutron is not included in the spectrum.

* Now at Newark College of Engineering.
[1] B. T. Darling, Phys. Rev. 80, 460 (1950).
[2] E. Schrödinger, Proc. Roy. Irish Acad. 47, 1 (1941).
[3] M. Born, Revs. Modern Phys. 21, 463 (1949).
[4] P. R. Zilsel, Phys. Rev. 82, 557 (1951).
[5] P. H. Fowler *et al.*, Phil. Mag. 42, 1040 (1951); P. E. Hodgson, Phil. Mag. 42, 1060 (1951).
[6] R. Armenteros *e al.*, Phil. Mag. 42, 1113 (1951).

I9. On Uniqueness in the Theory of Fundamental Length.* B. T. DARLING, *Ohio State University* AND P. R. ZILSEL, *University of Connecticut*.—The invariant operator of displacement by the timelike interval

$$2\omega,\ f(u)=2J_1(2\omega u)/2\omega u,\ (u=\partial/\partial x_\sigma), \tag{1}$$

which was obtained originally* as the average of a noninvariant operator over the rotation group in four dimensions, can be derived uniquely from simple considerations: Such a displacement operator must satisfy $[\Sigma(\Delta x_\sigma)^2+4\omega^2]f=0$ or, in the u representation

$$(\Sigma\partial^2/\partial u_\sigma^2+4\omega^2)f=0, \tag{2}$$

the "reciprocal"[1] Klein-Gordon equation. As was shown by Schrödinger[2] for the "ordinary" Klein-Gordon equation, the only invariant solution of (2) which satisfies the correspondence principle requirement* $f\rightarrow 1$ as $\omega\rightarrow 0$, is (1). General invariant nonlocal operators occurring in other theories can be expressed either in terms of (1), or in terms of the operator* $(2J_2+J_1)/z$ by Fourier-Bessel type integrals over ω and do not correspond to a well-defined fundamental displacement.

* B. T. Darling, Phys. Rev. **80**, 460 (1950).
[1] M. Born, Revs. Modern Phys. **21**, 463 (1949).
[2] E. Schrödinger, Proc. Roy. Irish Acad. **47A1** (1949).

I10. The Aether of Dirac in the Light of Contemporary Field Theory. Alexander W. Stern.—Because of the infinite energies existing even in weak coupling theories, Dirac has been prompted to experiment with field theories[1,2] where in the interaction is not treated as a perturbation. His new classical field theory[2] does not consider the electron apart from its interaction with the electromagnetic field. The recently rediscovered aether of Dirac[3] may be interpreted as interaction isolated as action, suggesting the well-known grin of the absent cat, except that here the grin exhibits a quantum-mechanical shape. By the introduction of this aether in his classical electromagnetic theory, Dirac has placed interaction on an equal footing with particle and field. Isolated particle, field, or interaction may be legitimately viewed only as theoretical idealizations. It is instructive to note certain aspects of similarity between the vacuum of quantum field theory and the aether in Dirac's classical theory. The properties of the aether with respect to the free electromagnetic field of his theory are such that it may be said to behave in the manner of a "quantized vacuum." Thus, the vacuum takes on dynamical properties in classical theory as well as in quantum theory. In classical theory the aether or vacuum exhibits velocity properties with respect to the electromagnetic field, while in quantum theory there are the vacuum field fluctuations with respect to the quantized electromagnetic field.

[1] P. A. M. Dirac, Nuovo Cimento **7**, 925 (1950).
[2] P. A. M. Dirac, Proc. Roy. Soc. (London) **A209** (1951).
[3] P. A. M. Dirac, Nature **168**, 906 (1951).

I11. The Cell Method in the Grand Canonical Ensemble. John M. Richardson and S. R. Brinkley, Jr., *U. S. Bureau of Mines.*—Starting with the Kirkwood[1] formulation in the petit canonical ensemble, the cell method of classical statistical mechanics is generalized to the case of the grand canonical ensemble. The summation over the possible states of a system then factors into a product of independent summations over the states of individual cells. Here the term "state" is used in an extended sense including numbers of particles of each type as well as their representative points in phase space. If the distribution function is approximated by a product of factors, each depending upon the state of each cell, it is possible to obtain a generalized form of the free-volume theory of liquids for the case of mixtures. To obtain this, the pressure is maximized with respect to the cell size and the functional form of each factor keeping the temperature and chemical potentials fixed. A special application of this method will be discussed in the following paper. In the limit of zero cell size, an interesting alternative formulation of statistical mechanics is obtained.

[1] J. G. Kirkwood, J. Chem. Phys. **18**, 380–382 (1950).

I12. Application of the Cell Method in the Grand Canonical Ensemble to the Equation of State of a Liquid Mixture. S. R. Brinkley, Jr., and John M. Richardson, *U. S. Bureau of Mines.*—The theory of the last paper is explicitly applied to the derivation of the equation of state of a liquid mixture. Use is made of the pressure maximization principle using an approximate factorization of the distribution function into factors dependent upon the states of individual cells. In the cell states, only vacancies and single occupancies are considered. As usual, the free volume of component α may be defined as the partition function (in the petit canonical sense) of a cell singly occupied by a molecule of type α with the interaction with surrounding cells averaged over their states. Using the Lennard-Jones potential function and the Lennard-Jones Devonshire[1] approximation to the average interaction, the equation of state for mixtures is obtained in a form employing only previously tabulated functions.[2] The most satisfactory cell size is obtained by maximizing the pressure with respect to this quantity. This theory is satisfactory only if the molecules are nearly the same size. The problem of greatly different molecular size will be discussed.

[1] Lennard-Jones and Devonshire, Proc. Roy. Soc. (London) **A163**, 53 (1937); **165**, 1 (1938).
[2] Wentorf, Buehler, Hirschfelder, and Curtiss, J. Chem. Phys. **18**, 1484 (1950).

I13. The Relation of Monte Carlo and Variational Calculation Methods in Quantum Mechanics. J. K. Bragg, *General Electric Research Laboratory.*—The Monte Carlo method for the calculation of the eigenvalues of Schrödinger's equation involves the solution of the corresponding diffusion equation (with creation and destruction) by a sampling procedure. The continuous diffusion paths are replaced by discretized paths of a finite number of steps in this process. It will be shown that, for a large number of steps, this method becomes equivalent to that of minimizing the ordinary variational integral by a trial method.

Thursday Afternoon at 2:15

Shoreham, Terrace Room

(S. A. Korff presiding)

Invited Papers on New Cosmic-Ray Particles

IA1. Some Recent Studies of *V*-Particles. R. B. Leighton, *California Institute of Technology.* (40 min.)

IA2. *V*-Particles. W. B. Fretter, *University of California, Berkeley.* (40 min.)

IA3. Report on Recent Work at Bristol University, England. E. P. George, *Birkbeck College.* (40 min.)

FRIDAY MORNING AT 9:15

NBS, East Building Lecture Room

(R. G. BRECKENRIDGE presiding)

Mostly Non-Metallic Crystals

J1. Electron Scattering Experiments at Low and Middle Energies.* L. MARTON, *National Bureau of Standards.*—An instrument has been built for the observation of the velocity and angular distribution of scattered electrons from solid scatterers. In the present arrangement a well-collimated beam of electrons is directed onto the target, the orientation of which is adjustible with five degrees of freedom. Beam energies between 0.1 and 15 kev have been used to date. Provisions have been made for extension of this energy range up to 150 kev. A magnetic analyzer for the scattered beam is mounted on a turntable which carries the detector. The analyzer can cover an angular range of about 330 degrees, exclusive of a back scattering angle of ±15 degrees. Early experiments show that the analyzer has an energy resolution of about one percent. Design features and preliminary scattering experiments will be discussed.

* Work supported by the ONR.

J2. (Abstract withdrawn.)

J3. A Mechanism Causing Variations of the Axial Ratio in Noncubic Metallic Crystals. JOHN B. GOODENOUGH, *University of Chicago.*—A mechanism is proposed to show how the Fermi surface exerts a force of attraction on the Brillouin zone boundaries. The direction and relative magnitude of the variation of the c/a ratio for hexagonal crystals from the ideal value for close packing are predicted as a function of the electron-atom ratio, and these predictions are compared with values of lattice parameters which are reported in the literature.

J4. Internal Fields in Crystals. E. T. JAYNES, *Stanford University.*—Many years ago, Ewald[1] developed a method for numerical calculation of internal fields at any given point in a crystal lattice, by means of a transformation which converts a slowly converging sum over lattice points into a rapidly converging one. In this way one obtained various Lorentz factors relating internal field at specified points to polarization caused by a particular lattice of dipoles. In recent theoretical treatments of ferroelectricity[2] and dielectric properties of crystals, refinements have been introduced which make use of the internal fields throughout a certain region of the unit cell, rather than at isolated points, and a new method for numerical evaluation is needed. Taking advantage of symmetry properties of the internal fields, the potential due to a lattice of multipoles may be found as the solution of a boundary-value problem, and expressed as an expansion in orthogonal functions. In this way the fields at nearly all points within the unit cell are given by a single expression which, by proper choice of the base functions, can be made to converge as rapidly as do the Ewald sums. In practice, this means that two or three terms in the sum give all the numerical accuracy that can be used in present theories.

1 P. P. Ewald, Ann. phys. **64**, 253 (1921).
2 M. A. Cohen, Phys. Rev. **84**, 368 (1951).

J5. Six-Dimensional Representation of Stress and Strain in a Face-Centered Cubic Crystal. A. V. HERSHEY, *Naval Proving Ground.*—Stress and strain may be represented by six-dimensional vectors whose squares are scalar invariants of the three-dimensional stress and strain tensors. If the covariant components of shear are twice the contravariant components of shear in the six-dimensional vectors, then the conventional elastic constants are represented by a six-dimensional tensor whose covariant or contravariant matrices are symmetric. The work of deformation is the scalar product of the stress and the increment of strain. The resolved shear stress in a plastic slip system is the scalar product of the stress and the strain per unit slip. There are twelve slip systems in a face centered cubic crystal, there are 349 plastic states with different sets of shear stresses equal to the slip stress, and there are 954 plastic states with independent sets of active slip systems. Only twenty-three plastic states need to be analyzed in detail because of symmetry. The stress-strain relations of the plastic crystal can be summarized by compact six-dimensional formulas.

J6. The Interaction of Excitons and Phonons. PAUL LEURGANS AND J. BARDEEN, *University of Illinois.*—The interaction between excitons and phonons is examined to determine the mean free path of thermal excitons for scattering by lattice waves. Using the idea of deformation potentials,[1] we compute the magnitude of the interaction from the change in band gap with dilation. From the values of the change in band gap given in reference 1, the mean free path in Ge is found to be 103A at 300°K and 3000A at 10°K. In NaCl, the known thermo-optic behavior is used to evaluate the band gap shift, from which the mean free path is found to be 12A at 300°K. Also considered are second-order effects caused by electric fields, arising either from energy band shifts in non-polar semiconductors (Ge) or from "polarization waves" in polar crystals. The resulting polarization interactions are found to be small compared to the interactions arising from the change in band gap.

1 J. Bardeen and W. Shockley, Phys. Rev. **80**, 72 (1950).

J7. Piezoelectricity, Ferroelectricity, and Crystal Structure.* A. VON HIPPEL, *M.I.T.*—By visualizing polar crystals as a network of permanent dipole moments, the piezo- and ferroelectric properties of dielectrics may be derived from the standpoint of molecular symmetry. This approach is used to clarify the relation between the sphalerite and wurtzite structures, the ferroelectric feedback effect in barium titanate, aspects of domain formation, and the interrelationship between ferro- and piezoelectricity.

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

J8. Some Dielectric Properties of Barium-Strontium Titanate Ceramics. LUTHER DAVIS, JR., AND LAWRENCE G. RUBIN, *Ratheon Manufacturing Company.*—Dielectric properties of ceramics of barium titanate, strontium titanate, and some mixtures of the two have been studied. A plot of the Curie temperatures *vs* weight percent showed an essentially linear relationship. The dielectric constant ϵ'/ϵ_0 of some mixtures was measured as a function of temperature at frequencies of 1 kc, 10 kc, 500 kc, and 3000 mc with no frequency dependence apparent at temperatures above the Curie point. ϵ'/ϵ_0 for 73 $BaTiO_3-27$ $SrTiO_3$ was measured as a function of applied dc field and temperature for both low and microwave frequencies. Such data showed a decrease of ϵ'/ϵ_0 and an increase in the temperature of the Curie point with an increase in field. A null detection microwave bridge determined the phase and amplitude of the 10 cm wave propagated through the ceramic sample in the coaxial mode. The linearity of a Curie Weiss plot was used to ascertain the electrical length of the sample. Use of samples of various lengths verified these results. The loss tangent ($\tan\delta$) at 3000 mc showed an increase over its low frequency values. However, above the Curie point, these values were not so large as to preclude the possibility of using titanate materials as circuit elements in microwave devices.

J9. Comparative Elastic Studies of Single Crystals of the CaF_2 and CsCl Types.* LEWIS S. COMBES, STANLEY S. BALLARD, AND KATHRYN A. MCCARTHY, *Tufts College.*—Values for Young's modulus, apparent elastic limit, and modulus of rupture have been reported[1] for several crystals of the NaCl type. Additional data have been obtained on these three properties for five more crystals: calcium fluoride, barium fluoride, cesium bromide, thallium chloride, and thallium bromide-iodide (KRS-5). The measurements were made in flexure, as before, on bars cut from single crystals. Typical stress-strain curves will be shown. For both calcium fluoride and barium fluoride the elastic limit and modulus of rupture were found to coincide, i.e., Hooke's law is obeyed to the point of rupture. Measurements made on bars of thallium bromide-iodide, each cut with its long axis approximately 10° from a 100 direction in the crystal, give values of 2.3×10^{11} dyne cm^{-2} for Young's modulus and 73×10^{7} dyne cm^{-2} for apparent elastic limit. These values are considerably larger than those previously reported:[2] 1.6×10^{11} and 26×10^{7} dyne cm^{-2} for Young's modulus and apparent elastic limit, respectively, obtained for a bar cut with its long axis approximately in a 110 direction.

* This work has received support from the Permanent Science Fund of the American Academy of Arts and Sciences.
[1] At the New York meeting of the American Physical Society on February 2, 1952.
[2] Combes, Ballard, and McCarthy, J. Opt. Soc. Am. **41**, 215 (1951).

J10. X-ray Absorption in the Calcite Crystal.* GUENTER SCHWARZ AND GEORGE L. ROGOSA, *Florida State University.*—Recently Campbell[1] has shown that in crystals set at the Bragg angle, the transmitted intensity is higher than one expects from the absorption coefficient of the material. Most of this work was done using CuKα radiation. Bragg has found that at short wavelengths the intensity transmitted through rock salt decreases when the crystal is set at the Bragg angle. Experiments have been performed on calcite crystals of various thicknesses at wavelengths from 0.7A to 2.3A. Monochromatization was obtained using a double crystal spectometer. The results of Campbell and Bragg can be confirmed. However, at 0.7A, for example, we find that when the crystal is rotated through the Bragg angle, the transmitted intensity may increase or decrease depending on the crystal thickness. In some cases the transmitted intensity differs depending on whether the angle at which the radiation falls on the crystal is smaller or larger than the Bragg angle. At the Bragg angle the intensity goes through a minimum and then through a maximum.

* This work was supported by the Research Corporation.
[1] H. N. Campbell, J. Appl. Phys. **22**, 1139 (1951).

J11. Theory of Optical and Thermal Transitions in Solids. RYOGO KUBO, *University of Chicago.*—Let $F(\Delta E)$ be the probability density of a transition process with the jump of energy equal to ΔE in the presence of a perturbation H'. Then the Laplace-transform of F is generally expressed in the form, $L_\lambda F=\text{trace}[\rho(\beta-\lambda)H'\rho(\lambda)H']/\text{trace}\ \rho(\beta)$, where ρ is the density matrix and λ is the generating parameter.[1] The trace should be taken in a subspace properly chosen to fit the physical nature of the unperturbed states. This method is applied here to optical and thermal transitions of electronic states in solids. At high temperature limit we have naturally the semiclassical pictures usually adopted on the basis of Frank-Condon principle and activated state theory of reaction rates. At low temperatures wave-mechanical interference effects dominate. If the atomic motions are assumed to be harmonic, the normal modes differing between different electronic states, the calculations are easily carried out, and if only the optical modes are included we reach at once the results of Huang and Rhys.[2] Applications are also discussed to nonpolar crystals.

[1] R. Kubo, J. Chem. Phys. (to be published).
[2] K. Huang and A. Rhys, Proc. Roy. Soc. (London) **204**, 406 (1950).

J12. Theory of the Shape and Width of Bands in the Vibrational Spectra of Crystals. THOMAS H. WALNUT, *The University of Chicago.*—A method has been found for relating the width and shapes of observed vibrational bands of perfect crystals to the anharmonic part of the potential function. In formulating this method it was necessary to develop a new way of treating mechanical anharmonicity in crystals in terms of the moments of the observed frequencies above given points. General expressions are given for these moments as a function of temperature and approximate relations have been found for special cases in molecular and ionic crystals. The basis functions used in the treatment were harmonic oscillator functions whose coordinates were the crystal normal coordinates that most closely approximated the true potential function at a given temperature.

J13. Micellar Structure in Silicate Glass. A. F. PREBUS, *The Ohio State University,* AND J. W. MICHENER, *Owens-Corning Fiberglas Corporation.*—Electron transmission micrographs of glass show that several silicate glasses possess inhomogeneities in composition on a scale greater than that postulated by Zachariasen[1] and by Warren.[2] A glass of composition: $SiO_2-54.6$ percent; $Al_2O_3+Fe_2O_3-14.8$ percent; $CaO-17.4$ percent; $MgO-4.5$ percent; $B_2O_3-8.0$ percent; $Na_2O+K_2O-0.6$ percent; possesses sinuous or helical chain structures having widths of about 30A and lengths of several hundred A. Fine flame blown fibers of the same glass possess silica chains of greater length and these are aligned with the fiber axis. A glass of composition: $SiO_2-63.6$ percent; Al_2O_3 -3.8 percent; $Fe_2O_3-0.2$ percent; $CaO-14.0$ percent; $MgO-2.6$ percent; $B_2O_3-6.7$ percent; $Na_2O-8.7$ percent; $K_2O-0.4$ percent; possesses similar aggregates which tend to form rods in parallel alignment. The second phase of these glasses appears homogeneous and flows readily at fractured surfaces.

[1] W. H. Zachariasen, J. Am. Chem. Soc. **54**, 3841 (1932).
[2] Warren, Krutter, and Morningstar, J. Am. Ceram. Soc. **19**, 202 (1936); B. E. Warren, J. Am. Ceram. Soc. **24**, 262 (1941).

J14. Dynamic Behavior of Nylon Filaments.* D. J. MONTGOMERY AND W. G. HAMMERLE, *Textile Research Institute.*—Stress-relaxation measurements with 30-denier (6.1×10^{-3} cm diameter) drawn 6,6-nylon filaments at fixed elongations of 1–2 percent showed the stress decay to be approximately linear in the logarithm of the time. From this relationship the behavior of the material in forced or free oscillation can be calculated. To verify the predicted behavior, free oscillations of a torsional pendulum supported by the filament were observed in the range 0.001 to 0.1 vibration per second. As usual, the results are expressed in terms of a Voigt model consisting of Hookean spring and Newtonian dashpot in parallel. The observed dependence of the spring constant and the viscosity on frequency agreed satisfactorily with the predicted form. The Voigt model has only the most limited physical validity; for it may be shown that the viscosity force fails to be proportional not merely to the first derivative of the displacement, but indeed to any derivative or integral of the displacement.

* Supported by the ONR.

FRIDAY MORNING AT 9:30

Shoreham, Terrace Room

(L. M. LANGER presiding)

Radioactive Nuclei from Gallium Onward

JA1. Gamma-Rays in the Decay of Ga^{66}. L. G. MANN AND W. E. MEYERHOF, *Stanford University.*—A 3-crystal scintillation pair spectrometer of the type suggested by Hofstadter has been used to study the gamma-rays in the decay of 9.2-hr Ga^{66}. The Ga^{66} was produced in the Berkeley 60″ cyclotron by the $Zn(p, n)$ reaction and was chemically separated. Gamma-rays with the following energies (in Mev) and relative intensities, corrected for pair cross section, were found: 4.78(0.03), 4.43(0.02), 4.29(0.08), 3.79(0.07), 3.38(0.10), 3.21(0.06), 2.75(1.00), 2.43(0.2), 2.20(0.3), 1.93(0.2), and possibly 1.39(0.1). The gamma-ray energies were also checked, as far as possible, by a single crystal pair spectrometer and the strong 1.05-Mev gamma-ray was found, but no gamma-rays of lower energy were noticed. The gamma-rays can be fitted, in approximate agreement with beta-decay intensities, into the following system of levels of Zn^{66}: 4.78, 4.43, 4.29, 3.79, 3.25, 2.43, and 1.05 Mev. These levels are in agreement with a decay scheme of Ga^{66} suggested by Preiswerk and Mukerji (private communication) except for the 4.3-Mev level which seems to be double and a 2.75-Mev level which is replaced here by a 2.43-Mev level. A suggested decay scheme of Ga^{66} will be discussed.

JA2. Beta-Gamma Angular Correlation in As^{76}. S. L. RIDGWAY AND F. M. PIPKIN, *Princeton University.*—Differential beta-gamma angular correlation has been investigated with selection of beta-energy in a magnetic spectrometer arrangement similar to that of Stevenson and Deutsch,[1] but with all magnetic shielding at the photomultipliers. The results for Rb^{86} agree with those of Deutsch,[1] for As^{76} the coefficient a of the angular correlation $1+a\cos^2\theta$ rises from $+0.04\pm0.02$ to $+0.07\pm0.03$ from 1.4 to 2.0 Mev. With the decay scheme determined by the spectrometer evidence, the result cannot be fit by a single beta-matrix element in any interaction. The situation seems to require an interpretation on the basis of interference of matrix elements as was done by Fuchs[2] for the case of Rb^{86}, and an interpretation on this basis will be discussed. This work was supported in part by the AEC.

[1] D. T. Stevenson and M. Deutsch, Phys. Rev. **83**, 1202 (1951).
[2] M. Fuchs, thesis, University of Michigan (1951).

JA3. Additional Branch in the Decay Scheme of Zr^{89m}.* F. J. SHORE, H. N. BROWN, W. L. BENDEL, AND R. A. BECKER, *University of Illinois.*—The 4.4-minute[1] isomeric state, produced by probe irradiation of Zr metal and ZrO_2 in the 22-Mev betatron, has been found using a scintillation spectrometer to be accompanied by a 1530-kev gamma-ray. Coincidences were observed between a particle group and gamma-rays of energy greater than 600 kev. Al absorption of the radiations in the particle counter yielded a maximum particle energy of about 850 kev on comparison with positrons from 79-hour Zr^{89} and Na^{22}.[2] This is the approximate energy to be expected for a positron group going from Zr^{89m} to an excited state of Y^{89} at 1530 kev above its ground state. The intensity of the 1530-kev gamma-ray is about 7 percent that of the 586-kev gamma-ray emitted in the transition from Zr^{89m} to the ground state of Zr^{89}. The intensity ratio remained constant with the following were varied: isotopic composition of the source,[2] betatron energy (14, 17.5, 22 Mev), probe material (Pb, Cu), and irradiation geometry. This, together with the 4.4-minute half life, confirms that $Zr^{90}(\gamma, n)Zr^{89m}$ is the process leading to the 1530-kev gamma-ray branch.

* Supported in part by the joint program of the AEC and ONR.
[1] Shore, Bendel, and Becker, Phys. Rev. **83**, 688 (1951).
[2] Na^{22} and enriched Zr^{90} supplied through the kind cooperation of the AEC at Oak Ridge.

JA4. Radioactivity in Ruthenium 103.* J. M. LEBLANC, F. B. STUMPF, W. H. NESTER, AND J. M. CORK, *University of Michigan.*—It has been generally agreed that the 40-day radioactivity in ruthenium is ascribable to mass 103 and consists of two beta- and two gamma-rays. By use of both the fission product and specimens irradiated in the pile, it appears from spectrometric studies that there are several additional previously unreported gamma-rays. The gamma-energies as found are—39.6, 52.9, 295.2, 598.5, and 610.6 kev in addition to certain other lines due to Ru 106. An obvious level scheme is presented together with the K/L ratios for two of the gamma-rays and the suggested multipolarities of the transitions.

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

JA5. Radioactivity of Pd^{111}. CARL L. MCGINNIS, *University of California, Berkeley.*—A 20-Mev deuteron bombardment of palladium has produced a 5.5-hr Pd activity which has a 2.15-Mev beta-spectrum associated with it. The 7.5-day Ag^{111} has been extracted chemically from a 5.5-hr Pd parent which assigns this new activity to Pd^{111m}. The 27-min ground state of Pd^{111} decays with a 2.15-Mev beta-spectrum to an excited state of Ag^{111} whose 60-kev conversion electrons have been observed. On the basis of the shell model the following assignments are made: Pd^{111m} h 11/2, Pd^{111} d 5/2, Ag^{111m} 7/2, and Ag^{111} p 1/2.

JA6. The Decay of the Cd^{115} Isomers. R. W. HAYWARD, *National Bureau of Standards.*—By use of a magnetic lens and a scintillation spectrometer the radiations from the 2.3-day and 43-day Cd^{115} isomers were studied. The 2.3-day isomer decays by two beta-groups with upper energies of 1.12 ± 0.01 Mev (~60 percent) and 0.60 ± 0.02 Mev (~40 percent) and the 43-day isomer by three groups of 1.63 ± 0.01 Mev (~98 percent), 0.7 Mev (~2 percent), and a weaker branch at 0.35 Mev. Besides the 335 ± 1 and 525 ± 5-kev gamma-transitions an additional cascade of 360 and 500-kev gammas was found in the disintegration of the 2.3-day Cd by coincidence and scintillation spectrometer measuremens. The 4.5-hr state of In^{115} is not involved in this latter cascade. Gamma-rays of 1280, 950, 500, and 450 kev are present in the decay of the 43-day Cd^{115}. The relative intensities of these gamma-radiations, together with shell model considerations, lead to a level scheme in In^{115} as follows: ground state, $g_{9/2}$; 335 kev, $p_{1/2}$; 500 kev, $d_{5/2}$; 860 kev, $d_{3/2}$; 950 kev, $g_{7/2}$; and 1280 kev, $h_{11/2}$. The 2.3-day state of Cd^{115} is 1.45 ± 0.01 Mev above the ground state of In^{115}, and the 43-day Cd^{115} level is 180 ± 10 kev above the 2.3-day state.

JA7. Effect of the Electron Shell on Angular Correlations.* JAN C. KLUYVER AND MARTIN DEUTSCH, *M.I.T.*—The results of Frauenfelder *et al.*[1] on the effect of the chemical state of a source of In^{111} on the angular correlation of the gamma-rays emitted in its decay were confirmed. In addition we find that sources of dilute $In_2(SO_4)_3$ solution give a correlation of the form $W(\theta)=1-0.19\cos^2\theta$ very similar to that obtained with the best metal sources. Sources of dry indium sulfate give a nearly isotropic correlation as do sources of the oxide. The interest of this observation lies mainly in the fact that solution sources are much easier to prepare and more reproducible than the metallic films previously considered necessary for obtaining unperturbed correlations.

* Supported in part by the joint program of the ONR and AEC.
[1] Frauenfelder, Phys. Rev. **82**, 549 (1951); Aeppli, Bishop, Frauenfelder, Walter, and Zünti, Phys. Rev. **82**, 550.

JA8. Radiations from Sn^{125}.* R. I. MENDENHALL, C. E. MANDEVILLE, E. SHAPIRO, E. R. ZUCKER,† AND G. L. CONKLIN, *Bartol Research Foundation.*—Targets of polyisotopic raw tin and of isotopic Sn^{124} (isotopic concentration 95 percent) have been irradiated on four occasions in the Oak Ridge pile. Chemical separations were performed for the removal of Sb, Te, and other impurities. By aluminum absorption the beta-rays of the 10-day Sn^{124} were measured to have an energy of ~2.3 Mev. Coincidence absorption revealed the presence of a hard gamma-ray at 1.67 ± 0.10 Mev which decayed with the 10-day period.‡ The beta-gamma coincidence rate of Sn^{125} decreased to zero at ~170 Mc/cm^2 in aluminum, suggesting that an inner beta-ray group at ~0.5 Mev is in immediate coincidence with the hard gamma-ray. By placing lead before the gamma-ray counter, $e^- - \gamma$ coincidences from any contaminating 15-day Sn^{117m} were shown to be absent.

* Assisted by the joint program of the ONR and AEC.
† Frankford Arsenal.
‡ Also observed at Oak Ridge. G. E. Boyd *et al.*, Supplement 2, NBS circular 499, p. 33.

JA9. Properties of the Nuclear Levels Associated with the Decay of Sb^{122}.* MICHAEL J. GLAUBMAN AND FRANZ R. METZGER, *University of Illinois.*—2.8*d* Sb^{122} was found to decay by beta-emission to the ground state and to 0.56- and 1.24-Mev excited states of Te^{122}. All three beta-ray spectra can be classified as first forbidden. The transition to the ground state belongs to the $\Delta I=2$, yes, group. Assuming spin zero and even parity for the ground state of the even-even Te^{122} nucleus, we have to assign spin two and odd parity to the Sb^{122} ground state. This is consistent with the combination of a $g_{7/2}$ proton and an $h_{11/2}$ neutron. The K conversion coefficient of the 0.56-Mev gamma-ray was determined as 0.49 ± 0.04 percent, which unambiguously characterizes the transition as electric quadrupole, and the first excited state in Te^{122} as 2, even. A 0.68-Mev transition leads from the 1.24-Mev excited state to the 0.56-Mev level. In the angular correlation between the 0.68- and 0.56-Mev gamma-rays the coefficient of the $\cos^2\theta$-term is negative, that of the $\cos^4\theta$-term positive. The only cascade leading to a zero spin ground state that will agree with the measured correlation is the 2–2–0 one. The 2–2 transition is mixed, 80 percent being electric quadrupole, 20 percent magnetic dipole.

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

JA10. Erbium 165. D. N. KUNDU, J. D. SERVICE, AND M. L. POOL, *Ohio State University*, AND G. E. BOYD, *Oak Ridge National Laboratory.*—A proton bombardment of holmium was reported[1] to yield a 10-hour activity in the erbium fraction decaying solely by the emission of electromagnetic radiation. Others,[2] however, did not obtain this activity in the erbium fraction from a 19-Mev deuteron bombardment of holmium. An activity of 9.9 ± 0.1-hour half-life measured over a period of 5 half-lives has been produced from a 7.4-Mev proton bombardment of a column separated sample of Ho_2O_3 and also of a high purity Hilger material. This activity decays with the emission of holmium K_α x-rays, gamma-rays, and conversion electrons. The aluminum absorption end points approximated electron energies of about 0.22 Mev and also 1.1 Mev in smaller amounts. A 10-Mev deuteron bombardment of holmium also indicated the production of the above activity. Under such deuteron bombardment other activities, e.g., the 27-hour Ho^{166}, are produced in such excessive amounts that the 9.9-hour x-ray emitter was much obscured and was observed only after a careful analysis of a series of absorption measurements. This activity is, therefore, assigned to Er^{165}.

[1] F. D. S. Butement, Proc. Phys. Soc. (London) **63A**, 775 (1950).
[2] G. Wilkinson and H. G. Hicks, UCRL-677.

JA11. Gamma-Radiation from Platinum.* J. M. CORK, J. M. LEBLANC, F. B. STUMPF, AND W. H. NESTER, *University of Michigan.*—The many electron lines arising from the internal conversion of the gamma-radiation emitted by platinum irradiated in the pile may be divided into three significant groups. Certain of the lines decay with the well-known half-life of 17.4 hr ascribed to Pt 197, having work functions characteristic of gold and indicate the same two gamma-rays of energy 77.6 and 191.4 kev found in the K capture decay of Hg 197. Another group with K–L–M differences characteristic of mercury arise from the formation of Au 199, which decays with a half-life of 3.4 days with beta-emission followed by three gamma-rays of energy 49.6, 158.8, and 208.3 kev. A third remaining group of electron lines with half-life about 4 days, appear to have work functions characteristic of platinum. It is, therefore, believed that the gamma-rays indicated, arise from isomeric transitions in platinum. Their energies are 98.3 and 129.6 kev, agreeing with the gamma-energies found for a long lived 180-day gold activity. It would thus appear that there is probably no 4.4-day activity in Pt 193 decaying by K capture to Ir 193. The K/L intensity relationships and the multipolarity of the transitions are given for several of the gamma-rays.

* This project received the joint support of the AEC and ONR.

JA12. Angular Correlation of Gamma-Rays in Pt^{194}.* CHARLES E. WHITTLE AND PHILIP S. JASTRAM, *Washington University.*—The angular correlation function has been determined for the cascaded gamma-rays resulting from transitions between the first two excited states of Pt^{194}. The correlation functions, together with the assumption that the ground state of Pt^{194} (even-even) has zero spin, indicate that one transition is dipole and the other is quadripole and yield for the spins of the first three states of Pt^{194} the choce of values 0–1–2 or 0–2–2. An attempt to correlate this information with the beta-decay of Ir^{194} is in progress.

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

JA13. Radiations of Tl^{204}.* L. LIDOFSKY, P. MACKLIN, AND C. S. WU, *Columbia University*.—The radiations of Tl^{204} have been investigated in this laboratory. In addition to the previously reported beta-emission, Hg x-rays resulting from decay by K-capture have been found. The beta-spectrum was studied using the magnetic solenoid spectrometer with vacuum evaporated sources. The spectral shape observed agreed with that of a simple spectrum whose shape corresponds to that of B_{ij} matrix element. The end point observed was 765 ± 10 kev. The shape is in agreement with that predicted by shell structure theory if a large pairing energy is assumed for high angular momentum nucleons. A search for possible gamma-rays with a NaI scintillation spectrometer revealed a radiation of ~70-kev energy. The use of a critical absorption technique identified the radiation as x-rays of mercury. The number of x-rays per β-particle was determined as ~2 to 3 percent.

* This work was supported by the AEC.

JA14. A Determination of the Half-Life of Am^{242m} for Negative Electron Emission.* THOMAS K. KEENAN, ROBERT A. PENNEMAN, AND B. B. MCINTEER, *Los Alamos Scientific Laboratory*.—A precise value of the above half-life was determined yielding 16.01 ± 0.02 hours. Ten samples were each followed over more than $7\frac{1}{2}$ half-lives. Mathematical treatment of the counting data is described.

* Work done under auspices of the AEC.

FRIDAY MORNING AT 9:30

Shoreham, West Ballroom

(J. A. HIPPLE presiding)

Symposium of the DCP on Mass-Spectroscopy

K1. Effect of Mass on Dissociation-Probability and Study of Dissociation-Processes with Conditioned Isotopes. O. A. SCHAEFFER, *Brookhaven National Laboratory*. (30 min.)

K2. Interpretation of Mass-Spectra in Terms of Molecular Structure. H. EYRING, A. L. WAHRHAFTIG, AND H. M. ROSENSTOCK, *University of Utah*. (30 min.)

K3. Ion-Molecule Collisions as a Tool in Chemical Physics. M. H. INGHRAM, *University of Chicago*. (25 min.)

K4. Flame Studies with a Rapid Sampling Mass Spectrometer. S. N. FONER AND R. L. HUDSON, *Johns Hopkins Applied Physics Laboratory*. (20 min.)

K5. Appearance-Potentials and Ionization-Probability Studies by Electron-Impact. R. E. FOX, W. M. HICKAM, T. KGELDAAS, JR., AND D. J. GROVE, *Westinghouse*. (25 min.)

K6. A Detailed Study of Appearance-Potential Curves. S. N. FONER, F. T. MCCLURE, A. KOSFIAKOFF, AND D. P. EASTER, *J. H. A. P. Laboratory*. (20 min.)

FRIDAY MORNING AT 9:30

Shoreham, Main Ballroom

(A. V. ASTIN presiding)

Radio-Carbon Dating and Neutrons in the Atmosphere

KA1. Natural Radio Carbon and Radio-Carbon Dating. W. F. LIBBY, *University of Chicago*. (45 min.)

KA2. Survey of Neutron-Density and Neutron-Production in the Atmosphere. R. LADENBURG, *Princeton University*. (35 min.)

KA3. Further Experiments on Cosmic-Ray Neutrons. S. A. KORFF, *New York University*. (35 min.)

KA4. Latitude and Time Variations of Cosmic-Ray Neutrons. J. A. SIMPSON, *University of Chicago*. (35 min.)

FRIDAY MORNING AT 9:30

Wardman Park, Continental Room

(C. C. LAURITSEN presiding)

Reactions of Transmutation, I

L1. Identification of the Reaction $p+d\rightarrow\pi^++t$. RICHARD MADEY, KENNETH C. BANDTEL, WILSON J. FRANK, AND BURTON J. MOYER, *University of California, Berkeley*.—The method of identification of the reaction $p+d\rightarrow\pi^++t$ consists of studying the angular and energy correlations of pion-triton coincidences. A CD_2-C difference counting rate was obtained at one pair of correlated angles. The difference in the counting rates from CD_2 and C targets disappeared when the pion telescope was moved backward and forward of the predicted correlated angle by an amount equal to the angular resolution of the pion detector. Background interference was suppressed by means of time-of-flight requirements. For example, the difference in time of flight of elastically scattered protons and tritons from the target to the triton telescope is about two to three times the resolution time (5×10^{-9} sec) of the quadruple coincidence circuit used. The dead time of the scintillation counting equipment is designed to be of the order of 5×10^{-9} sec also. The spacing between successive radio-frequency proton beam pulses at full energy (340 Mev) is about 6×10^{-8} sec. The results of the most recent work will be presented.

L2. Cross Section of the $D(T, n)He^4$ Reaction for 80- to 1200-kev Tritons.* H. V. ARGO, R. K. ADAIR, H. M. AGNEW, A. HEMMENDINGER, W. T. LELAND AND R. F. TASCHEK, *Los Alamos Scientific Laboratory.*—A triton beam from the Los Alamos 2.5-Mev electrostatic accelerator entered a 1-cm long deuterium gas target through an aluminum window of thickness 1.5 mg/cm². The angular distributions of neutrons from the reaction $D+T=He^4+n+17.6$ Mev were observed with a BF_3 long counter for $E_T=377$, 574, 983, and 1206 kev, and zero degree measurements were made at energies down to 80 kev. The stopping power of the target window was determined by the location of the peak[1] in the reaction cross section. The maximum correction in the reaction cross section caused by scattering and energy straggling in the target window was 75 percent. The long counter absolute sensitivity was measured for 14-Mev neutrons by simultaneous counting of alpha-particles and neutrons from the reaction $T(d, n)He^4$ using a Cockcroft-Walton accelerator. The cross sections are 1.76, 4.93, 1.50, and 0.30 barns (all ±10 percent) at triton energies of 80, 165, 400, and 1200 kev, respectively. The resonance curve has been fitted by the Breit-Wigner nuclear resonance theory.

* This work was done under the auspices of the AEC.
[1] T. W. Bonner (private communication).

L3. Disintegration of Helium by 90-Mev Neutrons. P. TANNENWALD, *University of California, Berkeley.*—The cloud-chamber experiment described in a previous abstract[1] has been completed. A weighting factor was computed for each one- and two-prong star analyzed, which corrects for events which were too slanted to be measured. Since the number of He^3's was uncertain because they could not be distinguished from He^4's when the track did not end in the chamber, the ratio of He^3/pt events was assumed to be the same as the ratio of σ_{nn}/σ_{np} at 90 Mev. The total number of events, for neutrons above 20 Mev, was normalized to the interpolated n-He^4 total cross section of 1.9×10^{-25} cm².[2] The results are $\sigma_{\text{elastic}}=110\pm23$ mb, $\sigma_{pt}=35\pm5$ mb, $\sigma_{dt}=12.2\pm2.2$ mb, $\sigma_{pd}=11.9\pm2.5$ mb, $\sigma_{dd}=6.7\pm1.4$ mb, $\sigma_{pp}=0.5\pm0.25$ mb, $\sigma_{He^3}=13.7$ mb. The ratio of $\sigma_{\text{inelastic}}/\sigma_{\text{total}}$ is 0.42 ± 0.04. The angular distribution of scattered neutrons in the elastic collisions fits a Gaussian centered on the forward direction for incident neutrons with energies greater than 40 Mev and is roughly isotropic for neutrons below 40 Mev. Energy dependences and energy and angular distributions of the various disintegration products will be presented.

[1] P. Tannenwald, Bull. Am. Phys. Soc. **27**, No. 1, 54 (1952).
[2] Cook, McMillan, Peterson, and Sewell, Phys. Rev. **75**, 7 (1949).

L4. Excited States of the Lithium Isotopes.* W. FRANZEN AND J. G. LIKELY, *Princeton University.*—The energy distribution of particles emitted on proton bombardment of a thin lithium foil has been examined by means of a scintillation counter particle spectrometer. This spectrometer employs NaI crystals permanently mounted in a sealed dry housing on a photomultiplier tube. The energy response of the crystals was studied by bombarding them with protons of various energies. Particle spectra were thus recorded at 30°, 60°, 90°, 120°, and 150° in the laboratory system. Identification of particles was accomplished by observing the dependence of their energy on the angle of observation, and by measuring the slope of their range-energy curve at a known energy by means of thin aluminum foils. At a bombarding energy of 18.3 Mev and with an energy resolution of 3 percent, inelastic scattering of protons from levels in Li^7 at 4.5 and 6.5 Mev was observed. The level at 6.5 Mev appears to have a considerable natural width. A level in Li^6 at 2.1 Mev gives rise both to an inelastic group of protons and to a group of deuterons from the reaction $Li^7(p, d)Li^6$. In addition, deuteron groups corresponding to transitions to the ground state and a 3.6-Mev excited state of Li^6 were observed. The deuteron group which leaves Li^6 in the ground state is evident at all forward angles up to 90° in the laboratory system.

* This work was supported by the AEC.

L5. Disintegration of Li^6 by Fast Neutrons.* F. L. RIBE, *Los Alamos Scientific Laboratory.*—The cross section of the $Li^6(n, \alpha)H^3$ reaction has been determined at neutron energies of 2.49 and 14.2 Mev. Targets of Li^6F (2.49-Mev case) and Li^6 metal (14.2-Mev case) were bombarded inside a proportional counter filled with krypton sufficient to stop the tritons and alpha-particles whose energy spectrum was determined by means of a multichannel pulse-height analyzer. This energy spectrum served both to identify the reaction products and to determine the cross section. The values obtained for the cross section at 2.49 and 14.2 Mev were 188 and 26 millibarns, respectively, with an error of ±14 percent. Earlier measurements by Blair *et al.*[1] indicated a steady decrease with energy of this cross section from the resonance at 0.27 Mev to about 0.8 Mev. The present values are consistent with a continued monotonic decrease of $\sigma(E_n)$ with neutron energy to 14.2 Mev. At 14.2 Mev, in addition to the (n, α) reaction products, a large group was observed from the competing (n, d) and (n, p) processes, of which ~140 millibarns can be attributed to the ground-state reaction $Li^6(n, d)He^5$.

* Work performed under the auspices of the AEC.
[1] See Robert K. Adair, Revs. Modern Phys. **22**, 249 (1950).

L6. Energy of Be^7 and B^{10}.* FAY AJZENBERG, *University of Wisconsin.*—Recent results on the angular distribution of the neutrons from the 3.5-Mev deuteron bombardment of thin targets of Li^6 oxide and of metallic beryllium will be discussed. The neutrons were detected by means of nuclear emulsions, 100 and 200 microns thick, placed at 10 cm from the targets and at angles ranging from 0° to 80° to the incident beam. 4600 proton recoil tracks measured at seven angles indicate, by application of Butler's theory,[1] that the ground state and the first excited state of Be^7 are of odd parity. No level corresponding to the 4.62-Mev[2] level in the mirror nucleus Li^7 has been observed. However, the continuum from the three-particle breakup of Be^8 would obscure any neutron group of low intensity. 1400 tracks from the $Be^9(d, n)B^{10}$ reaction have been measured so far at four of six angles. These preliminary results indicate that the first four states of B^{10} are of even parity.

* Work supported in part by the AEC and in part by the Wisconsin Alumni Research Foundation.
[1] S. T. Butler, Proc. Roy. Soc. (London) **A208**, 559 (1951).
[2] Gelinas, Class, and Hanna, Phys. Rev. **83**, 1260 (1951).

L7. Angular Distributions of (d, p) Reactions.* CLAYTON F. BLACK, *M.I.T.*—Theories by Butler,[1] and by Tobocman and Friedman[2] give the angular distribution of protons from (d, p) reactions. Since the distribution is unique for a given orbital angular momentum of the captured neutron, the measurement of the distribution of a given energy group yields

TABLE I.

Reaction	Level	Measured orbital angular momentum
$Be^9(d, p)Be^{10}$	ground state	$l_n=0$
	3.37 Mev	$l_n=1$
$C^{12}(d, p)C^{13}$	ground state	$l_n=1$
	3.1 Mev	$l_n=0$
	3.9 Mev	$l_n=2$

information about the position of single particle levels in the resultant nucleus. Measurements on carbon and beryllium have been made with 14.5-Mev deuterons from the M.I.T. cyclotron. A 5° to 10° shift to larger angles of the experimental curves from the theory can be accounted for from the effect of the Coulomb field. The results are summarized in Table I.

* This work has been supported in part by the joint program of the ONR and AEC.
[1] S. T. Butler, Proc. Roy. Soc. (London) A208, 559 (1951).
[2] Tobocman and Friedman (private communication).

L8. Angular Correlation in the $Be^9(d, p)Be^{10*}(\gamma)Be^{10}$ Reaction. L. COHEN, S. M. SHAFROTH, C. M. CLASS, AND S. S. HANNA, *Johns Hopkins Univeristy.**—Radiation from the 3.36-Mev state in Be^{10} was observed in coincidence with the short-range protons in the $Be^9(d, p)Be^{10*}(\gamma)Be^{10}$ reaction. Deuterons of 0.84 and of 0.91 Mev were used to initiate the reaction in thin beryllium targets. Detection was by means of NaI (Tll) crystals and photomultiplier tubes. For the charged particle detection a thin crystal was mounted in the vacuum of the target chamber. Energy resolution was used in connection with both counters in order to restrict the counting rates chiefly to the radiations under observation. With the proton counter fixed at 90° to the beam, the coincident yield was detected as a function of the angle of the gamma-counter at 15° intervals. Separate runs were made in which the angle subtended by the gamma-counter was 15°, 23°, and 30°. The observed correlation function, which shows a definite departure from isotropy, includes terms in $\cos^2\theta$ (negative) and $\cos^4\theta$ (positive). The form of the correlation was rather insensitive to the change in the angle subtended by the gamma-counter, indicating that higher order terms were not important. This result is consistent with the assignment of a spin of 2 to the excited state in Be^{10} in agreement with a majority of the assignments in other even-even nuclei.

* Assisted by a contract with the AEC.

L9. Ionization Measurement of $B^{10}(n, \alpha)Li^7$. J. RHODES* AND W. E. STEPHENS, *University of Pennsylvania.*†—A thin layer of boron on the wall of an argon-filled cylindrical ionization chamber exposed to slow neutrons has been used to study the ionization produced by the recoiling particles of the transmutation $B^{10}(n, \alpha)Li^7$. Polonium alpha-particles were used for calibration and the ionization electron pulses were amplified and photographed on an oscilloscope screen. Calculated peak shapes taking into account wall effect and layer thickness were fitted to the experimental number pulse-height curves and the ionization values deduced. Peaks resulting from lithium nuclei formed in the ground state as well as the excited state and the corresponding alpha-particles were resolved. The ratio of ionization produced by the He^4 and Li^{7*} recoils was observed to be 1.878 ± 0.014 compared to the energy ratio 1.7529 determined from conservation of momentum. This difference can be accounted for with the assumption that the average energy per ion pair varies with velocity in a manner similar to that described by Hanna.[1] The average energy per ion pair relative to polonium alpha-particles was found to be 1.02 ± 0.01 for the alpha-particles and 1.09 ± 0.01 for the Li recoils.

* May Amanda Wood Research Fellow.
† Supported in part by the joint program of the ONR and AEC.
[1] G. C. Hanna, Phys. Rev. 80, 530 (1950).

L10. B^{10} and O^{16} Reaction Energies.* D. S. CRAIG,† D. J. DONAHUE, AND K. W. JONES, *University of Wisconsin.*—Q values of the reactions resulting from the proton bombardment of B^{10} and deuteron bombardment of O^{16} have been measured electrostatically as described by Williamson *et al.* Estimates have been made of the differential cross sections of these reactions at a laboratory angle of 135°. The rms error quoted is the square root of the sum of the square of all errors, both statistical and systematic, entering into the measurements. The $O^{16}(d, \alpha)N^{14}$ Q value, which is crucial in the computttion of nuclear masses from reaction energy data, agrees well with the two previous measurements of this value. The energy of the first excited state in B^{10}, obtained by the inelastic scattering of protons, indicates that the value obtained from gamma-ray energy measurements should not be corrected for a Doppler effect.

TABLE I.

Reaction	Q(Mev)	Error rms	Error Limit	$\frac{d\sigma}{d\omega}\times10^{26}$ cm²/steradian	Bombarding energy Mev
$O^{16}(d, He^4)N^{14}$	3.113	0.0035	0.0055	0.9	0.893
$B^{10}(p, He^3)Be^8$	−0.536	0.003	0.004	0.1	3.421
$B^{10}(p, He^4)Be^7$	1.147	0.0025	0.0044	2	3.333
$B^{10}(p, He^{4\prime})Be^{7*}$	0.717	0.0026	0.0043	1	3.333
$B^{10}(p, p')B^{10*}$	−0.719	0.0016	0.003	0.3	2.191

* Work supported in part by the AEC.
† Now with Atomic Energy of Canada, Ltd., Chalk River, Ontario.

L11. The $B^{11}(p, n)C^{11}$ Angular Distribution. H. B. WILLARD, J. K. BAIR, AND J. D. KINGTON, *Oak Ridge National Laboratory.*—The angular distribution of neutrons from the reaction $B^{11}(p, n)C^{11}$ has been studied from threshold (3.015 Mev[1]) to 5 Mev. A thin (50 kev at 3 Mev) target of natural boron was bombarded with the analyzed beam of protons from the 5.5-Mev Van de Graaff, and the neutrons were detected with a long counter located at one meter. The resonances previously reported[2] at 3.17, 3.75, and 4.67 Mev were observed at all angles, and in addition, the level at 4.14 Mev was resolved into two narrower ones. The absolute value of the cross section was obtained by calibration of the long counter with a standard source. The value found at the peak of the 3.75-Mev resonance is 5.44 ± 0.50 mb per steradian. The center-of-mass distributions have been fitted with a series expansion of $\cos\varphi$. The total cross section was obtained by integration. An attempt will be made to deduce the spins of the levels excited in the compound nucleus.

[1] Richards, Smith, and Browne, Phys. Rev. 80, 524 (1950).
[2] H. B. Willard and J. K. Bair, Bull. Am. Phys. Soc. 27, No. 1, ZB7 (1952).

L12. $(n, 2n)$ Reactions in C^{12}, Cu^{63}, and Mo^{92}.* J. E. BROLLEY, JR., J. L. FOWLER,† AND L. K. SCHLACKS, *Los Alamos Scientific Laboratory.*—We have employed the $D+T$ reaction to produce neutrons with energies up to 27 Mev. The deuterons were accelerated in the cyclotron to 11 Mev and focused in a gaseous tritium target. The elements measured were irradiated in the form of thin foils whose angular position with reference to the incident deuteron beam determines the neutron energy. The copper and molybdenum foils were encased in thin cadmium jackets. The $(n, 2n)$ reactions were detected by positron activity. Small K-capture corrections in copper and molybdenum, but not in carbon, were made. For carbon we have measured the $(n, 2n)$ cross section at a few points near the threshold and at 27 Mev where it is about 10×10^{-27} cm². The case of copper is especially interesting since it may be compared with the theory of Weisskopf and collaborators. An excellent fit to the data is obtained up to 16 Mev where the theory begins to give higher values than the experiment. Proton competition was ignored in the theoretical calculation and may contribute to this discrepancy. The molybdenum cross section will also be compared with the theory.

* Work done under the auspices of the AEC.
† Now at ORNL, Oak Ridge, Tennessee.

L13. Products of Carbon Disintegration by 330-Mev Protons.* WALTER H. BARKAS AND J. KENT BOWKER, *University of California, Berkeley*.—The spallation fragments of $H\rho \approx 4.5 \times 10^5$ gauss-cm leaving a one-mil polystyrene target in the forward direction are brought to a 180° focus in the magnetic field of the 184-inch cyclotron. The spalls enter the surface of Ilford D_1 nuclear track emulsion making a small angle with the surface. The position, track-angle, range, and estimate charge are recorded for each track. The calculated radius of curvature plotted against the range provides a nuclide spectrum of the tracks, since each nuclide falls on a definite locus in such a diagram. Resolution of H^1, H^2, H^3, He^3, and He^4 splinters is unambiguous. A group probably comprising Li^6 and Be^7 and another group probably of He^6 and Li^7 are also found, but for lack of good range-energy curves for highly charged particles the resolution is at present uncertain. No Li^8, B^8, $H^{>3}$ or $He^{<3}$ tracks were found. The abundances of the fragments are as follows: H^1, 25.0 percent; H^2, 7.4 percent; H^3, 4.6 percent; He^3, 7.0 percent; He^4, 41.5 percent; (Li^6, Be^7 group), 3.3 percent; (He^6, Li^7 group) 4.9 percent; other groups plus background, 6.2 percent. Further measurements in other momentum intervals and with other targets are in progress.

* This work was supported by the AEC.

L14. Levels of N^{14} Observed from $C^{13}(d, n)N^{14}$.* R. E. BENENSON, *University of Wisconsin*.—An approximately 30-kev thick carbon target enriched to 61 percent C^{13} was bombarded by 3.9-Mev deuterons. The resulting groups of neutrons corresponding to levels in N^{14} and N^{13} were detected by means of Eastman NTA emulsions placed at seven angles ranging from 0° to 80° with respect to the incident beam. A total of 2000 tracks have been measured so far at three angles and work continues. Levels up to 8.1-Mev excitation energy were observed in N^{14}, including some previously unreported levels above 5.7-Mev excitation energy. An attempt will be made to assign parities and possible spin values to some of the low-lying levels of N^{14} according to the analysis of S. T. Butler[1] of the stripping process. The parity of the ground state of N^{14} is of particular interest in connection with the forbiddenness of the beta-decay of C^{14}, and it is hoped that with better statistics this parity value may be determined.

* Work supported in part by the AEC and the Wisconsin Alumni Research Foundation.
[1] S. T. Butler, Proc. Roy. Soc. (London) **A208**, 559 (1951).

FRIDAY MORNING AT 9:30
Wardman Park, Burgundy Room
(V. F. WEISSKOPF presiding)

High Energy Nuclear Processes (Theoretical)

M1. Interactions of 150-Mev Protons with the Nucleus $A=100$.* S. J. LINDENBAUM, *Brookhaven National Laboratory*, AND G. BERNARDINI, *Columbia University*.—It was previously reported[1] that the inelastic interactions of 300–400-Mev neutrons and protons with emulsion nuclei were in agreement with Goldberger model predictions. At lower incident energies the model may be expected to be less reliable since the DeBroglie wavelengths and range of scattering force of the moving nucleons increase. Also more of the cascade collisions occur at energies only a few times the nuclear potential and hence binding and other nuclear structure effects might interfere. To test the model for 150-Mev protons the previously reported Monte Carlo cascade techniques were utilized to evaluate 200 interactions with the nucleus $A=100$. The calculations were refined in several respects, notably the step-by-step distinction of neutrons and protons throughout the cascade. The results will be compared to the calculations for 400-Mev protons and to preliminary experimental data for the interaction of 150-Mev protons with G-5 emulsion (mainly Ag−Br nuclei of average $A=100$). Mr. Leon Landovitz and Mr. Jack Leitner performed the Monte Carlo computations.

* Jointly sponsored by AEC and ONR.
† Now at the University of Illinois.
[1] Bernardini, Booth, and Lindenbaum, Phys. Rev. **83**, 669 (1951); and Phys. Rev. (to be published).

M2. High Energy Nuclear Photoeffect.* ISRAEL REFF, *Indiana University*.—Research has been done on the absorption by nuclei of photons of 200 Mev energy and higher results in the formation of stars.[1] The total cross section for this process has been calculated by second-order perturbation procedure, treating the interactions phenomenologically. The process is assumed to consist of two steps: (1) absorption of photon by nucleus with production of a meson by interaction of photon with a single nucleon; (2) subsequent reabsorption of meson by the same nucleus. In this reabsorption, the meson interacts with two nucleons which recoil leading to subsequent excitation of the nucleus. The calculation will be compared with the experimental results.

* Associated by the joint program of ONR and AEC.
[1] R. D. Miller, thesis, University of California.

M3. Meson Exchange Contributions to the High Energy Deuteron Photoeffect. R. H. HUDDLESTONE AND J. V. LEPORE, *University of California, Berkeley*.—Recent measurements at Berkeley[1] and elsewhere[2] on the photodisintegration of the deuteron between 140 and 290 Mev yield a cross section which appears to be an order of magnitude larger than that expected on the basis of the usual photoelectric dipole and quadrupole contributions. The size of the cross section suggests that meson exchange phenomena may play an important role at these energies. An attempt has been made to estimate these effects on the basis of the pseudoscalar meson theory with gradient coupling. It is important to note that not all exchange effects in this theory can be interpreted as due to exchange currents. Furthermore, the energy and angular dependences do not correspond to electric dipole disintegration alone so that it is not possible to treat these processes by the use of Siegert's theorem. The meson exchange diagrams are treated nonrelativistically in the initial nucleon momenta by using a deuteron wave function in the initial state. The results for a value of $f^2/4\pi \sim .1$ are in approximate agreement with the mildly rising energy dependence of the observed total cross section and the differential cross section is not inconsistent with experiment.

[1] W. S. Gilbert and J. W. Rose, Bull. Am. Phys. Soc. **26**, No. 8, 18 (1951).
[2] T. S. Benedict and W. M. Woodward, Bull. Am. Phys. Soc. **27**, No. 1, 54 (1952).

M4. The "Nucleon Isobar" as an Intermediate State. N. AUSTERN,* *Cornell University.*—Some preliminary attempts have been made to extend the isobar model of the interaction of a π-meson with a nucleon[1] to high energy processes involving two nucleons, following recent suggestions of Bethe and Wilson.[2] Such processes are assumed to proceed by two steps, with the first step being in each case the excitation of one nucleon to its isobar state. Collisions of the "second kind" are envisaged, in which the excited nucleon collides with its neighbor in such a way that the energy of excitation becomes energy of relative motion of the nucleons. The cross section for deuteron photodisintegration has been computed according to this model, using as input data the $\pi^+ + H^2$ capture cross section, the $\pi + P$ scattering cross sections, and the $\gamma + P \rightarrow \pi^0$ cross section. The angular distribution in photodisintegration has the form $(1+(\frac{3}{2})\sin^2\theta)$, and the cross section has a magnitude which is in rough agreement with the recent high energy measurements.[3]

* AEC Postdoctoral Fellow.
[1] Brueckner and Case, Phys. Rev. **83**, 1141 (1951). Brueckner, Bull. Am. Phys. Soc. **27**, No. 1 (1952).
[2] Private communications. R. R. Wilson, Phys. Rev. **86**, No. 1 (1952).
[3] Gilbert and Rose, Phys. Rev. **85**, 766(A) (1952). Benedict and Woodward, Bull. Am. Phys. Soc. **27**, No. 1 (1952).

M5. Concerning a Tentative Hypothesis of Proton Isomers. G. BREIT, *Yale University.**—It has been suggested[1] that high energy $p-p$ scattering would be easier to explain if protons had isomers. The explanation mentioned the possibility of ^3S scattering without detail. The upper limit for the total cross section in terms of $\lambda\!\!\!^-{}^2$ does not depend on whether one has a one or two channel reaction and the possibility of having ^3S scattering helps only because it enables states with higher L to give S states. $^3P_1$ states give $^3S_1$ states if the isomer is assumed to have spin $\frac{1}{2}$ and odd parity. The statistical weight of $^3P_1$ being three times that of $^1S_0$ there results the statistical factor 4. A more quantitative consideration indicates the likelihood of an appreciable effect of $^3P_1$ scattering which results if one attempts to account for a large $^3S_1$ amplitude. There should be, besides, transitions from $^3F_2$ to $^3D_2$, $^3H_4$ to $^3G_4$, and their intensity is hard to predict. Complete spherical symmetry is, therefore, not expected even on the isomer hypothesis. Isomers of even parity and spin $\frac{1}{2}$ do not give ^3S waves. Spherical symmetry can result in these cases only as a cancellation effect.

* Assisted by the joint program of the ONR and the AEC.
[1] G. Breit, Phys. Rev. **84**, 1053 (1951); G. Breit and H. M. Jones, Phys. Rev. **84**, 1054 (1951).

M6. Interpretation of High Energy $p-p$ Scattering. DON R. SWANSON, *University of California, Berkeley.*—High energy $p-p$ scattering has been interpreted by several authors in terms of highly singular noncentral interactions. The triplet state calculations were carried out in the Born approximation and, together with the singlet, yielded an almost isotropic (c.m. system) differential cross section. Agreement with experiment was good at large angles but the theoretical peak in the forward direction, due mostly to singlet D scattering, was too large. It is not clear, however, that the Born approximation should be valid for singular potentials. In the present analysis, the wave equation has been integrated numerically to obtain an exact solution at 350 Mev using the tensor interaction of Christian and Noyes. A "square well" cutoff at the nucleon Compton wavelength was used. In the case of the "repulsive" interaction, the triplet cross section agrees closely with the Born approximation for scattering angles greater than 25° but is larger at small angles. This remarkable agreement is apparently accidental since the $^3P_0$ and $^3P_1$ phase shifts are incorrect by orders of 50 percent in the Born approximation. The "attractive" triplet cross section is about 30 percent larger at 30° than at 90°, and is therefore inconsistent with the experimental data even at large angles. The influence of the cutoff is under further study. The exact phase shifts here obtained will be used to calculate polarization effects in a double $p-p$ scattering.

M7. Polarization Effects in $P-P$ Scattering at High Energies.* L. J. B. GOLDFARB AND D. FELDMAN, *University of Rochester.*—The inclusion of a spin-orbit coupling in the interaction between two protons implies that, in a $p-p$ scattering experiment, the outgoing particles are polarized. This polarization can be detected by performing a second scattering, since the resultant intensity will then exhibit an azimuthal asymmetry, i.e., $I(\vartheta, \phi) = I_0(\vartheta)[1+\delta(\vartheta)\cos\phi]$. Calculations of these effects for various potentials[1] by means of the Born approximation lead to a vanishing polarization.[2] More exact calculations show that at 240 Mev the predicted unpolarized cross sections are strongly modified, largely because of the singular nature of the potentials which must be cut off if a solution is to exist. For the tensor force, phase shifts corresponding to $J=0$, 1 were calculated exactly, others corresponding to $J \leqslant 5$ by Schwinger's variational treatment, while the rest were taken into account in Born approximation. One finds $\delta_{\max} \sim 0.01$. The $\mathbf{L}\cdot\mathbf{S}$ potential, on the other hand, leads to asymmetries $\delta_{\max} \sim 0.15-0.25$, although there is very poor agreement of the unpolarized cross section with experiment.

* Supported by the AEC.
[1] R. S. Christian and H. P. Noyes, Phys. Rev. **79**, 85 (1950); K. M. Case and A. Pais, Phys. Rev. **80**, 203 (1950).
[2] L. Wolfenstein, Phys. Rev. **82**, 308 (1951).

M8. Some Remarks Related to the Theory of the Pick-Up Process. GEORGE J. YEVICK,* *University of Maryland.*—Consider a particle, e.g., a proton, in a bound state determined by a fixed potential $U(\mathbf{r}_p)$ at $t=-\infty$. Now assume a free neutron incident on the bound proton which can interact with the proton via the potential $V(\mathbf{r}_n-\mathbf{r}_p)$. As $t\rightarrow\infty$, an inelastic scattering that can take place in that the neutron and proton travel off together in a bound state of $V(\mathbf{r}_n-\mathbf{r}_p)$. We have obtained the *time-independent* scattering equation for this process employing the methods of Lippmann and Schwinger.[1] It turns out to be necessary to use the unitary transformation operator $\exp[(-i/\hbar)(K+V)t]$, where K is the kinetic energy operator for the neutron and proton, and also to expand the initial state into the eigenfunctions of $K+V$. The S-matrix expression is straightforward to obtain but the rate of transition is somewhat ambiguous because of time oscillating factors. This ambiguity is understood using Dirac's method of variation of constants for a first order perturbation calculation. We shall compare our considerations with an elegant Green's function solution obtained by S. T. Epstein.[2]

* On leave of absence from Stevens Institute of Technology.
[1] B. A. Lippmann and J. Schwinger, Phys. Rev. **79**, 469 (1950).
[2] Private communication.

M9. Wave-Mechanical Description of the Deuteron Stripping Process. F. L. FRIEDMAN AND W. TOBOCMAN, *M.I.T.*—A wave-mechanical description of the deuteron stripping reaction $(d-p)$ in the binding energy range has been worked out neglecting the Coulomb field. The physical model is essentially the same as that used by Butler.[1] The formulation is adapted to the use of boundary conditions on the nuclear surface as in the single particle reaction theories. The results are interpretable in terms of single particle reaction parameters (e.g., neutron cross sections) and the deuteron wave function. Results include description of the capture of neutrons into low nuclear energy ststes and the scattering and capture by states available to free neutrons. Angular distributions in the first case agree with those of Butler,[1] and the absolute values of the cross sections are now given an explicit form.

[1] S. T. Butler, Proc. Roy. Soc. (London) **A109**, 559 (1951).

M10. Nuclear Forces Yielded by the Symmetrical Pseudoscalar Meson Theory with Pseudoscalar Coupling, JOSEPH V. LEPORE, *University of California, Berkeley*.—If one applies the transformation, e^{iS},

$$S[\sigma]=-(if/2\kappa_0)\int d\sigma_\mu\bar{\psi}\gamma_5\gamma_\mu\tau_\alpha\phi_\alpha\psi,$$

used by Dyson to the state vector in the interaction representation one finds that up to terms in $(f\mu/2\kappa_0)^2$ the pseudoscalar theory with pseudoscalar coupling is equivalent to a scalar pair coupling of a pseudoscalar field plus an ordinary pseudovector coupling of that field. These terms may be treated by the usual Feynman-Dyson techniques to yield the nuclear forces. The leading term in the Hamiltonian, $(f^2/2\kappa_0)\bar{\psi}\psi\phi_\alpha{}^2$, yields the main contribution to the radiative corrections to nuclear forces and, indeed, the main contribution to the forces themselves, provided f is not small. This force is the highly singular attractive spin independent, charge independent $(f^2/4\pi)^2(3\mu/4\pi\kappa_0{}^2r^2)K_1[2\mu r]$. Of the remaining terms in the Hamiltonian, in the form of a power series in $(f\mu/2\kappa_0)$, the leading term proportional to $(f\mu/2\kappa_0)$ yields the conventional pseudoscalar potential. In the strong coupling limit the scalar coupling term in the Hamiltonian dominates since it is proportional to $(f^2/2\kappa_0)$ and the pseudoscalar theory becomes not unlike a scalar theory.

M11. Low Energy Properties of Pseudoscalar Interaction with Hard Core. ROBERT JASTROW, *University of California, Berkeley*.—The properties of the nucleon-nucleon interaction are being examined on the assumption of a nucleon structure of approximate radius (r_0) 0.5×10^{-13} cm. The effects of this structure are described by an infinite repulsion in the interaction for $r<r_0$, along the lines of an earlier calculation by the author. An attempt is made to restrict phenomenology to the interior region $(r<r_0)$ by taking the interaction for $r>r_0$ to be determined by the symmetrical pseudoscalar theory with pseudoscalar coupling. This interaction is dominated by singular $(1/r^3)$ central and tensor attractive potentials coming from fourth- and second-order contributions in the pseudoscalar interaction.[1] Terms of higher order appear to be too short-ranged to make appreciable contributions for $r>0.50\times10^{-13}$ cm. The results of preliminary low energy calculations with $f^2/4\pi=11.5$ and core radii of 0.42 (triplet) and 0.46 (singlet) are as follows: effective range = 1.53 (triplet) and 2.70 (singlet); deuteron binding energy = 2.23 Mev; quadrupole moment = $+0.60\times10^{-27}$ cm²; singlet scattering length $=-23.8$. Lengths are in units of 10^{-13} cm.

[1] J. V. Lepore (this meeting).

M12. Scattering by High Potential Barriers and by Potentials with Shell Structure.* J. MAYO GREENBERG, *University of Maryland*.—The method developed by Hart and Montroll[1] for the scattering of plane scalar waves by relatively shallow spherical potential wells is extended to the cases of very deep wells and very high barriers. The limiting total cross section of an impenetrable sphere is correctly found to be, for high incident energy, exactly twice the geometrical cross section. The spherical Bessel function explansion of the wave functions is also applied to the scattering by a potential which consists of concentric wells or barriers; e.g., a Jastrow type potential. The series for the wave functions in the several regions obtained after applying the usual boundary conditions are summed by using asymptotic expressions for Bessel functions of large argument. It is hoped that the variational scheme[2] which was applied to the scattering by relatively shallow wells can also be applied to the scattering by shell structures.

* Work supported by the ONR.
[1] R. W. Hart and E. W. Montroll, J. Appl. Phys. **22**, 376 (1951).
[2] E. W. Montroll and J. M. Greenberg, Phys. Rev. (to be published).

FRIDAY AFTERNOON AT 2:00

Shoreham, Main Ballroom

(J. H. HOLLOMON presiding)

Metals

N1. Electromagnetic Levitation of Solid and Molten Metals. E. C. OKRESS, D. M. WROUGHTON, G. COMENETZ, P. H. BRACE, AND J. C. R. KELLY, *Westinghouse Electric Corporation*.—The subject is an unconventional method of heating and melting metals without a crucible. Operating conditions for certain cases are given. The results obtained by means of the new technique encourage the thought of melting, purifying, alloying, and agitation of inert and reactive metals without resort to crucibles, and thereby avoiding the contamination of reactive metals by crucible materials. Preliminary results with various forms and masses of metal are described. Considerations concerning the atmosphere in which levitation occurs are included.

N2. The Magnetic Susceptibility of Cb, Ta, V, Mo, and W at High Temperatures.* C. J. KRIESSMAN, JR., *U. S. Naval Ordnance Laboratory, and Catholic University*.—A furnace has been developed to extend the measurement of magnetic susceptibility to higher temperatures than those previously attained. The susceptibilities of Cb and Ta have been measured to about 1900°C. The susceptibility of Ta decreases from $.849\times10^{-6}$ at 25°C to $.685\times10^{-6}$ emu/g at 1870°C, while that of Cb decreases from 2.27×10^{-6} at 25°C to 1.71×10^{-6} at 1850°C. The susceptibilities of Mo and W have been found to increase with increasing temperature up to 1400°C. However, the susceptibility of V has been found to decrease with increasing temperature up to 1400°C, contrary to previous high temperature data.[1] Work is now in progress to extend all the measurements to 1900°C. A qualitative discussion of the data with reference to the band theory of metals is given.

* Supported in part by the ONR.
[1] K. Honda, Ann. Physik **32**, 1027 (1910).

N3. Measurement of Magnetostriction in Single Crystals. R. M. BOZORTH AND R. W. HAMMING, *Bell Telephone Laboratories*.—A simplified procedure is given for determining the 5 magnetostriction constants[1] of a single crystal of a ferromagnetic cubic crystal. The crystal is cut as a disk parallel to a (110) plane, and strain gauges[2] are cemented to the surfaces to measure strains in [001] and [1$\bar{1}$1] directions. A magnetic field sufficient for saturation is oriented in 10° steps at various angles to the [001] direction, and magnetostriction is measured over a 90° range for each gauge. Each of the 18 data is then multiplied by suitable numbers, obtained by inversion of the strain matrix, to give the constants $h_1\cdots h_5$ automatically adjusted to least square fit of the data. The method is applied to a rapidly cooled crystal of a 78 pecent nickel-iron alloy to determine the magnetostriction associated with spontaneous magnetization in the [111] direction: $\lambda_{111}=2h_2/3+2h_5/9$. This quantity is important in the "permalloy problem" because the magnetostrictive strain resulting from the movement of a boundary between two domains, magnetized parallel to [111] and [11$\bar{1}$], for example, depends on λ_{111} alone. In the crystal examined, $\lambda_{111}=1.7\times10^{-6}$.

[1] R. Becker and W. Döring, Ferromagnetismus 275 (1939).
[2] J. E. Goldman, J. phys. et radium **12**, 471 (1951).

N4. Single Crystal Magnetostriction Constants of an Iron-Cobalt Alloy.* H. M. A. Urquhart and J. E. Goldman, *Carnegie Institute of Technology.*—Magnetostriction constants were measured on a single crystal of 70 percent cobalt-iron alloy, the composition for which previous investigators[1] have observed the largest polycrystalline magnetostriction and which is, therefore, of particular theoretical interest. The measurements were made on a small ellipsoidal crystal ($a=b=.0244$ cm; $c=0.343$ cm; kindly loaned by Professor L. W. McKeehan) using the resistance strain gauge technique previously described[2] in which a gauge is cemented in a given direction on the crystal and the strain measured as a function of the angle made by the crystal with the applied magnetic field. Using Becker's notation, one readily obtains the constants h_1 and h_2. The other constants are negligible in this case. The values obtained are: $h_1=13.2\times10^{-5}$; $h_2=10.5\times10^{-5}\pm7$ percent in good agreement with Nesbitt's results corrected for the distribution in orientation of the crystallites. The small discrepancy between the respective results can be accounted for on the basis of composition differences, established quantitatively by the method of Koh[3] using fluorescent x-radiation.

* Supported by ONR and an Allegheny-Ludlum Research Fellowship.
[1] E. A. Nesbitt, J. Appl. Phys. **21**, 879 (1950); R. M. Bozorth, Ferromag.
[2] J. E. Goldman, Phys. Rev. **72**, 592 (1947); **80**, 301, 663 (1950).
[3] P. K. Koh and B. Caugherty, J. Appl. Phys. (to be published). We are indebted to the Allegheny Ludlum Research Laboratories for this analysis.

N5. The Hall Effect in Cobalt Above Magnetic Saturation. Simon Foner and Emerson M. Pugh.*—Precision measurements of the Hall Effect in pure cobalt have been made with an improved measuring system up to fields of 30 kilogauss. The value obtained for the ordinary[1] Hall constant was -1.33×10^{-12} volt-cm/amp-gauss at 14°C, which yields 0.52 effective conduction electrons/atom compared to 0.7 s electrons/atom obtained from magnetization data. No significant change was observed with respect to orientation for columnar cobalt. As pointed out previously,[2] the variation in the Hall potential *vs* magnetic induction is composed of two terms for ferromagnetics, one a function of the magnetization (dominant at low fields), the other a function of the magnetizing field (dominant above saturation). The initial slope of the Hall potential *vs* induction curve for cobalt, as observed previously,[3] is positive, which explains the positive Hall constant found in the literature. Experimental elimination of this magnetization term above saturation leads to an unambiguous sign and reasonable value of the ordinary Hall constant.

* Assisted by ONR.
[1] Pugh, Rostoker, and Schindler, Phys. Rev. **80**, 688 (0950).
[2] E. M. Pugh, Phys. Rev. **36**, 1503 (1930).
[3] A. W. Smith, Phys. Rev. **30**, 1 (1910); A. Kundt, Ann. Physik **49**, (1893); O. Zahn, Ann. Physik **14**, 886 (1904).

N6. Ordinary Hall Effect in Co–Ni Alloys. Emerson M. Pugh and Simon Foner.*—Measurements at room temperatures of the Hall Effect in the Co–Ni series of alloys have been made. The ordinary Hall coefficient is negative (as in the Ni–Cu series) throughout the range. The values agree, within a factor of 2, with values predicted from the assumption that from 0.6 to 0.7 s electrons per atom contribute to the conduction. This result is similar to that found by Schindler and Pugh in the ferromagnetic alloys of Cu–Ni. Except in the immediate region of pure Ni, the ordinary coefficient in these ferromagnetic alloys is larger than predicted so that the discrepancy cannot be explained by assuming any d band conduction.

* Assisted by ONR.

N7. Experiments on Electrical Conductivity. D. K. C. MacDonald, *National Research Council, Canada.*—Measurements on electrical resistance of the alkali metals have been made in a suitably modified Collins liquefier over complete temperature range from 300°K to 4°K. Rubidium[1] shows a particularly striking "transition" around 190°K, potassium and caesium also being anomalous in the upper temperature range while lithium and sodium are quite regular throughout. It is believed that some change in electronic structure is involved, perhaps similar to that proposed by Fermi and Sternheimer[2] to account for the volume transition in Cs under high pressure. Thermal expansion, thermoelectric power and magneto-resistance are also being measured. Measurements through the melting-point and in the liquid state also yield results of interest, particularly in relation to the change of characteristic temperature θ on melting.

[1] D. K. C. MacDonald, Phil. Mag. (to be published).
[2] E. Sternheimer, Phys. Rev. **78**, 235 (1950).

N8. Electrical Resistance of Tantalum. H. Preston-Thomas, *National Research Council, Canada.*—The electrical resistance of tantalum has been measured between room temperature and the superconductive transition point. The value of the Debye θ deduced from the slope of the resistance temperature curve is 210°K over a large part of this range (*cf.* 245° from specific heat measurements) while the unusually low value of the residual resistance ($R/R_0=.008$) indicates a high degree of physical and chemical purity; this was obtained by prolonged heating and prevention of subsequent distortion during measurement. A method of winding coreless coils of 5-cm length and internal diameter .03 cm allows ballistic and resistive measurements to be made on a single specimen in the superconducting region. These will be correlated with previous measurements on this metal[1] and with the concept of a "two-phase" model for the hard superconductors.[2]

[1] R. T. Webber, Phys. Rev. **72**, 1241 (1947).
[2] L. C. Jackson and H. Preston-Thomas, Phil. Mag. **41**, 1284 (1950).

N9. On θ-Values in Metals. F. M. Kelly and D. K. C. MacDonald, *National Research Council, Canada.*—While the work of Born, Blackman, and others indicates that the frequency distribution of the crystal lattice vibrations assumed by Debye is an oversimplification, the convenience of Debye's treatment has led to its wide application for the presentation of experimental data. The Debye θ_D's in the literature are usually derived from C_v as a function of temperature. Since $C_v=(\partial E/\partial T)_v$, and the resistance R is approximately proportional to the energy E, θ_D should strictly be compared with a θ_R derived from the slope of the resistance temperature curve, although it is also possible to base the derivation of θ_R on resistance ratios. The above methods assume that θ is independent of temperature. Alternatively, a θ_R rather more accurately descriptive of the lattice behavior may be calculated by recognizing θ as a temperature-dependent parameter in the theoretical expressions, and it may be argued that a comparison based on the total internal energy, i.e., the integrated specific heat is more realistic. Data for Li and K will be presented.

N10. Theory of Slip-Band Formation. John C. Fisher, Edward W. Hart, and Robert H. Pry.—The fine structure of slip bands at the surfaces of plastically deformed aluminum crystals, as described by Heidenreich and Shockley[1] and by Brown,[2] consists of slips of a thousand or so interatomic distances occurring on parallel slip planes that are separated by several hundred interatomic distances. This slip band structure can be explained in terms of the model of dislocation-loop generation proposed by Frank and Read.[3] First, there is a back-stress at an active Frank-Read source, produced by the expanding avalanche of dislocation loops radiating from it. Second, the back-stress from about 300 loops is shown to be sufficient to stop dynamic loop generation at the source. Slip, therefore, occurs in avalanches separated in time. Third, avalanches from other slip systems, crossing a slip plane containing an active source, lead to the observed stepped surface markings with successive avalanches from the given source arriving at the surface on different planes. This investigation was supported in part by the Flight Research Laboratory, Wright Air Development Center.

[1] R. D. Heidenreich and W. Shockley, J. Appl. Phys. **18**, 1029 (1947).
[2] A. F. Brown, J. Inst. Metals **80**, 115 (1951–52).
[3] F. C. Frank and W. T. Read, Phys. Rev. **79**, 722 (1950).

N11. Strain Hardening of Metal Crystals. Edward W. Hart, John C. Fisher, Robert H. Pry.—A simple mechanism is proposed to explain work hardening of metal crystals. Dislocation loops radiating from an active Frank-Read source bend about impenetrable impurity structures distributed in the slip plane, leaving trapped loops about the structures. The distributed trapped loop concentrations produce a back-stress throughout the plane, thereby raising the critical stress of all sources in the plane by that amount for continued plastic flow in the same direction. Conversely the critical stress is reduced for flow in the opposite sense, agreeing with the Bauschinger effect. The number of loops retained about each impurity structure depends on the spacing of the structures and the applied stress. When the external stress is removed, the loop concentrations expand, shedding the outermost loops and producing an elastic recovery. The plane is now initially somewhat softer for further slip, as is observed, since there are fewer trapped loops than before removal of the stress. The contraction and expansion of the loop concentrations under variations of the applied stresses appears further as a reduction of the elastic modulus. This investigation was supported in part by the Flight Research Laboratory, Wright Air Development Center.

N12. Measurement of the Internal Energy in Copper Introduced by Cold Work. Benjamin Welber, *Lewis Laboratory, NACA*.—The ratio of the stored energy E to the mechanical energy W expended in cold-working copper rods by twisting has been measured. E was determined by means of a refinement of the calorimetric technique employed by Quinney and Taylor[1] for similar measurements. The sample was placed in a vacuum chamber and its temperature raised steadily by means of a self-contained heater. A "guard ring" furnace was used inside the chamber to keep heat losses at a minimum. For each such run, the temperature was plotted against the heat supplied. Two runs were made for each cold-worked sample during the first of which the stored energy was released; comparison of the two curves permitted a determination of E. It was found that annealing was complete at 250°C. The results obtained for three values of W are shown.

W (cal/g)	E/W
8.2	0.028
9.4	0.030
11.9	0.034

[1] H. Quinney and G. I. Taylor, Proc. Roy. Soc. (London) **A163**, 157 (1937).

N13. Creep of Copper Under Deuteron Bombardment. Warren F. Witzig,* *Westinghouse Electric Company*.—The creep rate of copper under 16 Mev deuteron bombardment in the University of Pittsburgh cyclotron has been investigated. Theoretical considerations of the type discussed by Slater,[1] predict that with the available deuteron flux of 10^{12} particles per cm^2 per sec there should be no appreciable change in creep rate. So far as dislocations are concerned the available deuteron flux cannot displace sufficient atoms from their normal lattice sites to produce a dislocation; further, the steady-state density of displaced atoms is not sufficiently high to impede the motion of those dislocations. Arguments may be given to show that while regions of increased local temperature are produced during bombardment, these should not affect the creep rate. The experiments consisted of measurements of the second stage creep rate of a copper wire under deuteron bombardment at 260°C and a loading of 10,000 psi. Within the precision of the experiment, estimated to be ±20 percent, the creep rate during and after bombardments of 10 to 20 hours duration was unchanged from that preceding bombardment. Thus, apparently the type of considerations involved by solid state theory are confirmed and creep rates should not be expected to increase for all metals under bombardment as was feared a few years ago.[2]

* This paper is based on part of a thesis submitted in partial fulfillment of the requirements for the degree of Ph.D. at the University of Pittsburgh.
[1] J. C. Slater, J. Appl. Phys. **22**, 237 (1951).
[2] E. N. daC. Andrade, Nature, **156**, 113 (1945).

N14. A Weak Potential Model for Electrons in a Metal. Edward N. Adams II, *University of Chicago*.—Many properties of metals are qualitatively the same as the corresponding properties of a hypothetical degenerate electron gas. Thus in discussing metallic properties one often assumes that the electrons in a metal can be treated as noninteracting particles moving in some kind of average potential which has the periodicity of the space lattices. This potential is usually thought of as being weak in the sense that the distribution of energy levels is determined largely by the kinetic rather than the potential energy. In order to make a comparison of the properties of such a model with those of a real metal it is ordinarily necessary to calculate two things according to the model, *viz.*, the energy spectrum and the nondiagonal matrix elements of the momentum. An alternative procedure will be proposed in which the energy spectrum is assumed as a phenomenological fact. The most important effects due to off diagonal elements can be taken account of by a simple device which involves only an approximation expected to be very good in a weak potential theory.

N15. Self-Diffusion in Zinc.* H. B. Huntington, G. A. Shirn, and E. S. Wajda, *Rensselaer Polytechnic Institute*.—The self-diffusion of single crystal zinc has been measured from 300°C to the melting point with the use of Zn_{65} as a tracer and the usual lathe sectioning technique. Zinc 99.999 percent pure was furnished by the courtesy of the New Jersey Zinc Company. Only crystals whose figure axis lay within 10° of parallel or perpendicular to the hexagonal axis were used. Before plating each crystal was polished (or faced in a lathe), etched, electropolished and, after a preanneal, checked for grain boundaries. For diffusion parallel to the hexagonal axis the data were well fitted by an activation energy $Q=21.7$ kcal/mol and a $D_0=0.1$ cm^2/sec in good agreement with earlier investigators.[1] For diffusion perpendicular to the hexagonal axis somewhat preliminary results indicate $Q=25.4$ kcal/mole and $D_0=1.3$ cm^2/sec.

* Work performed under AEC contract.
[1] F. R. Banks, Phys. Rev. **59**, 376 (1941); P. H. Miller and F. R. Banks, Phys. Rev. **61**, 648 (1942).

FRIDAY AFTERNOON AT 2:15

NBS, East Building

(A. H. WHITE presiding)

Symposium of the DEP on Unusual Electron Physics

NA1. The Physics of Positronium. MARTIN DEUTSCH, *M.I.T.* (40 min.)

NA2. Some Properties of Fluorine-Contaminated Ice as Crystal Rectifier. E. J. WORKMAN, *New Mexico Institute of Mining and Technology.* (40 min.)

NA3. Electrodynamics of Magnetic Storms. D. H. MENZEL, *Harvard College Observatory.* (45 min.) (Illustrated).

FRIDAY AFTERNOON AT 2:15

Shoreham, West Ballroom

(J. O. HIRSCHFELDER presiding)

Symposium of the DCP on Chemical Transport Phenomena

P1. Relaxation Phenomena in Polyatomic Gases. K. F. HERZFELD, *Catholic University.* (45 min.)

P2. Quantum Corrections to the Transport Properties of Gases at Low Temperatures. R. B. BIRD, *University of Wisconsin.* (45 min.)

P3. The Statistical Mechanics of Transport Properties. J. G. KIRKWOOD, *Yale University.* (45 min.)

Business Session of the Division of Chemical Physics

FRIDAY AFTERNOON AT 2:00

NBS, Materials and Testing

(G. H. DIEKE presiding)

Optical Spectra; Molecular Structure

PA1. Excitation Characteristics of the Spectra of Highly Ionized Aluminum in the Low Pressure Spark. R. W. KEBLER,* W. W. MCCORMICK, AND R. A. SAWYER, *University of Michigan.*—The excitation of the spectra of three to six times ionized aluminum has been investigated in a controllable spark. The breakdown voltage was reproducible and adjustable at values from 5000 to 20,000 volts; the peak current, from 15,000 to 75,000 amperes; and the energy per train, up to a maximum of 6000 joules. Spectra were taken in the region from 95A to 3030A with a 6-meter vacuum spectrograph at grazing incidence. The intensities of lines arising from low states of the different spectra were plotted with respect to a strong line of Al IV as functions of the various discharge parameters. The relative intensity of Al V and Al VI lines increases as a function of current, at both constant frequency and voltage, but at a more rapid rate if the resistance in the spark circuit is increased. The relative intensity of the Al VII spectrum, shows an anomalous maximum of intensity of 30,000 amperes when the voltage is varied. A splitting of some of the Al IV lines with increasing current was observed which may be a Stark effect. The significance of some of these effects will be discussed.

* Now at Fort Monmouth, New Jersey, Signal Corps, U. S. Army.

PA2. The Continuous Spectrum of Molecular Hydrogen. G. H. DIEKE AND C. S. RAINWATER,* *Johns Hopkins University.*—The energy distribution in the continuous spectrum of H_2 has been determined for the region between 2200 angstroms and 3600 angstroms. The discharge tube pressure was varied from 0.6 to 15 mm Hg with currents from 0.06 to 2 amperes. The results show a higher relative intensity below 2500 angstroms than has been previously reported, and fail to indicate a maximum in the region observed. The changes in the distribution with variations in pressure and current were relatively minor. An explanation for this is suggested. The behavior of the distribution when an excess of helium is admitted to the tube was studied, and the depression of the short wavelength intensities verified. These facts are in agreement with the conclusion that the H_2 continuum is not due entirely to transitions from the $1s\sigma 2s\sigma\,{}^3\Sigma_g$ state to the unstable $1s\sigma 2p\sigma\,{}^3\Sigma_u$ state, but that some higher electronic states must also be involved. Analogy with corresponding transitions in the singlet system of H_2 suggests that the triplet $1s3d$ complex is possibly a principal contributor to the intensity in the shorter wavelengths of the continuum.

* Now at the University of Miami, Coral Gables, Florida.

PA3. Influence of Molecular Structure upon the Infrared Carbonyl Band in Polycyclic Quinones. MARIE-LOUISE JOSIEN AND NELSON FUSON, *Fisk University.*—Although many spectroscopic studies on the carbonyl stretching vibration have been made, the influence upon this vibration of the structure of the rest of the molecule is still not well understood. This is particularly true of polycyclic compounds containing the carbonyl group.[1] In order to contribute to the clarification of this problem an infrared spectroscopic study in carbon tetrachloride solution has been made of the C=O frequency in over one hundred quinones. The results will be compared with those obtained through other approaches to molecular structure such as the oxidation-reduction potentials,[2] the index of the C=O liaison,[3] the indices of free valence of the parent hydrocarbon,[4] and the geometrical form of the molecule.

[1] M. L. Josien and N. Fuson, Bull. Soc. Chim. France **19** (to be published 1952). This reference contains a bibliography on this subject.
[2] L. Fieser, J. Am. Chem. Soc. **57**, 493 (1935) and previous Fieser papers in the same journal.
[3] Pullman, Berthier, and Pullman, Bull. Soc. Chim. France **15**, 450 (1948).
[4] B. Pullman and A. Pullman, *Les Theories Electroniques de la Chimie Organique* (Masson & Cie, Paris, 1952).

PA4. Dissociation Energies of C—C and C—F Bonds in Several Fluorocarbons by Electron Impact. VERNON H. DIBELER, ROBERT M. REESE, AND FRED L. MOHLER, *National Bureau of Standards*.—Appearance potentials of the CF_3^+ ions in CH_3CF_3 (14.0 ev), C_2F_6 (14.3 ev), C_3F_8 (14.4 ev), n-C_4F_{10} (13.5 ev), and n-C_6F_{14} (14.4 ev) were measured with a mass spectrometer. Ionization efficiency curves of the fluorocarbon ions and the calibrating gas (argon) were plotted on semi-log paper. Appearance potentials were obtained from the measured intervals between the curves and the spectroscopic value for argon. The appearance potential of the CH_3^+ ion was also measured.[1] Assuming negligible excess energy in the dissociation process, the C—C bond energy was obtained by subtracting the known ionization potential of the CH_3 radical. This energy subtracted from the appearance potential of CF_3^+ gives the ionization potential of the CF_3 radical (8.9 ev). Subtracting the latter from the above appearance potentials gives an upper limit to the dissociation energy of the CF_3—R bond in the other four compounds. Excepting C_4F_{10}, this value is essentially constant (124 ± 7 kcal) within the estimated experimental error. The lower value for C_4F_{10}(106 kcal) is unexplained at present. Appearance potentials of $C_2F_5^+$ and $C_3F_7^+$ ions were also measured permitting estimates of the ionization potentials of these radicals and estimates of other C—C and C—F bond energies.

[1] Dibeler, Reese, and Mohler, J. Chem. Phys. (submitted for publication).

PA5. Wavelength Shift in Spectra of Aromatics Containing Fluorine.* H. SPONER, *Duke University*.—It has been observed that the electronic transition which occurs in benzene at 2600A shifts towards longer wavelengths upon substitution. This shift and the intensity of the absorption spectra have been discussed by several authors[1] in their dependence upon the resonance interaction between ring and substituent (migrational effect) and an inductive effect. It was found that for most molecules the resonance effect offers an adequate explanation of these properties. Exceptions were noticed for the phenylhalides and for benzotrifluoride where the order of intensities is opposite to predictions. The inductive effect was held responsible for this behavior. We have now observed that the red shift of the spectra is anomalous in the series fluorobenzene, meta difluorobenzene, 1,3,5-trifluorobenzene, in that it has the largest negative value for the monoderivative, is smaller for the diderivative and becomes positive for the triderivative. There are peculiarities also in the shifts of the corresponding spectra of other substituted benzenes containing fluorine atoms. These results will be demonstrated in tables and a discussion will be given.

* Supported by the ONR.
[1] K. F. Herzfeld, Chem. Revs. **41**, 233 (1947); A. L. Sklar, J. Chem. Phys. **7**, 984 (1939); F. A. Matsen, J. Am. Chem. Soc. **72**, 5243 (1950).

PA6. On the Absorption System of Light and Heavy Naphthalene Vapor at 2900–2500A.* C. D. COOPER, *University of Georgia*, AND H. SPONER, *Duke University*.—The second absorption region occurs in naphthalene at 2900–2500A. It was obtained in a 3-m grating spectrograph in Eagle mounting and consists of a succession of broad diffuse groups. Several of these groups show finer structure. The bands st 35,910 in light and at 36,035 cm^{-1} in heavy naphthalene are taken as 0, 0 bands of the system. The most prominent vibrational frequencies which appear in progressions and combinations are 480 and 1390 cm^{-1} in ordinary naphthalene, and 490 and 1365 cm^{-1} in deuterated naphthalene. Ground state vibrations of 512, 1022 cm^{-1}, and possibly 1380 are observed in the light compound, and of 495 in the heavy molecule. Here assignments of the higher frequency values to vibrational modes are uncertain. The region of overlap of the second absorption region with the first region at 3200–2800A makes measurements of these bands and their interpretations extremely difficult.

* This work was supported by the ONR.

PA7. The Near Ultraviolet Absorption Spectra of 2- and 3-Fluoropyridine in the Vapor State.* H. P. STEPHENSON, *Duke University* (*Introduced by* H. SPONER).—The near ultraviolet absorption spectra of 2- and 3-fluoropyridine have been photographed in the first order of a 3-meter grating spectrograph from 2200A to 3000A. It has been found that in two-fluoropyridine there is only one electronic transition in this region, whereas in three-fluoropyridine there are two transitions. The transition in two-fluoropyridine appears strongly with 0—0 band at 2628.35A (38,035.4 cm^{-1}) and has been assigned to a $\pi-\pi^*$ singlet-singlet electronic transition. It is characterized by a remarkable discreteness not possessed by the $\pi-\pi^*$ transitions in pyridine and other pyridine derivatives. Of the two transitions in three-fluoropyridine one is a strong system of very diffuse bands which appears in the same spectral region as the two-fluoropyridine spectrum. It has been assigned to a $\pi-\pi^*$ transition with 0—0 band probably at 2676.9A (37,346 cm^{-1}). The second system with 0—0 band at 2851.82A (35,055.1 cm^{-1}) is much weaker than the first and consists of extremely sharp, line-like bands. In analogy with pyridine, this latter transition has been assigned to an $n-\pi^*$ transition arising from a nonbonding electron of the nitrogen. Slides of the spectra will be shown and a probable explanation given for the absence of the $n-\pi^*$ transition in two-fluoropyridine.

* Supported by the ONR.

PA8. The Near Ultraviolet Absorption Spectrum of Meta Difluorobenzene.* V. RAMAKRISHNA RAO AND H. SPONER, *Duke University*.—The near ultraviolet absorption spectrum of meta difluorobenzene vapor was studied with a 3 m grating spectrograph in a pressure range corresponding to temperature of −60 to +25°C. About 400 bands were measured. They are degraded to the red. The strong band at 2637.1A was chosen as 0, 0 band. The most prominent frequencies appearing in the excited state are 703, 740, 967, and 1269 cm^{-1}. All of them are observed in strong bands also in the ground state.† Frequency differences of 66 and 97 cm^{-1} have been found representing $v-v$ transitions. A study of the spectrum in iso-octane solution gave $f=0.0096$ as oscillator strength, indicating a slight increase of the intensity over that of the monofluorobenzene spectrum.

* Supported by the ONR.
† A list of Raman frequencies (unpublished research) was very kindly supplied by Dr. J. Rud Nielsen.

PA9. Infrared Emission of the Hydrogen-Fluorine Flame. W. S. BENEDICT, *National Bureau of Standards*, B. W. BULLOCK AND SHIRLEIGH SILVERMAN, *Johns Hopkins Applied Physics Laboratory*, AND A. V. GROSSE, *Temple University*.—The radiation from a diffusion-type flame of fluorine in hydrogen, burning at pressures up to 5 atmospheres, has been observed using a Perkin-Elmer monochromator with quartz optics and PbS detector. The intensity of the HF emission bands in the fundamental region (2.25–2.75μ) is so great that spectral slits of ∼3 cm^{-1} could be used. The rotational structure of the R branches of the 1—0 and 2—1 bands is resolved out to $J''=16$, and heads are observed at 4412 and 4212 cm^{-1}

In the region of the first overtone, 1.25–1.65μ, spectral slits of $\sim$20 cm^{-1} permit resolution of rotational structure in the P branches of the $2-0$, $3-1$, and $4-2$ bands, and the observation of strong unresolved R-branch heads. With wide slits the $3-0$, $4-1$, $5-2$, $6-3$, and $7-4$ heads have been observed between $0.86-1.04\mu$. Improved values of the rotational constant D may be derived from the lines of high J. Rotational "temperatures" derived from the lines in the fundamental region where erratic due to reversal effects, but consistent vibrational "temperatures" of 4000$\pm$100°K have been obtained from the first overtone sequence.

PA10. Energy Distribution of CO Molecules in $CO-O_2$ Flames.* SHIRLEIGH SILVERMAN, *Johns Hopkins University, Silver Spring*.—The energy distribution in $CO-O_2$ flames in the CO harmonic region at 2.3 microns has been studied under moderately high resolution (slit width $\sim$0.8 cm^{-1}). "Temperature" profiles were obtained from a two-dimensional flame. Rotational "temperatures" were obtained from the usual $\ln I-\ln A$ *vs* E plots, as well as by comparing the integrated continuum intensity at the $2-0$ band head with the integrated intensity of several completely resolved lines at low J values. The vibrational "temperatures" were determined by plotting $\ln I\ |M|^2\nu^4/vs.\ E$ for a number of rotational lines in different vibration bands. Near the orifice, the rotational and vibrational "temperatures" are equal. The vibrational "temperatures" seem to correspond rather well to thermodynamic values throughout the profile. However, the rotational distribution gives evidence of a non-Boltzmann distribution over the entire flame beyond the region near the orifice. It is also noted that the maximum rotational and vibrational "temperatures" both occur in a region about 10^{-3} sec downstream from the reaction zone, with the rotational value somewhat the higher of the two. This would indicate then a probable equilibrium vibrational distribution for CO molecules, whereas rotationally, CO molecules are either excited by collision or formed by decomposition of CO_2 into higher rotational states than would be expected for thermal equilibrium.

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

PA11. Infrared Emission Spectrum of FeO. A. M. BASS AND W. S. BENEDICT, *National Bureau of Standards*.—A new band system ($F\rightarrow X$) has been observed in the near infrared in the radiation from flames to which iron carbonyl has been added. The system which extends from 7000 to 14000 cm^{-1} is attributed to a transition in FeO between the ground state and a low-lying electronic state. The 0, 0 band is located at 10332 cm^{-1} and a vibrational analysis shows the known spacing of about 864 cm^{-1} for the ground-state vibrational energy levels and about 651 cm^{-1} for the excited state. It appears likely that some of the bands previously measured and assigned by Malet and Rosen[1] to the system $D\rightarrow X$ are actually part of the short wavelength end of the new system.

[1] L. Malet and B. Rosen, Bull. Inst. roy. colonial belge., 377 (1945).

PA12. Centrifugal Distortion in Asymmetric Rotor Molecules.* D. KIVELSON AND E. BRIGHT WILSON, JR., *Harvard University*.—The effect of centrifugal distortion on the rotational energy levels of semirigid asymmetric rotor molecules of orthorhombic symmetry has been tretted by an approximation which is easier to use than the direct procedure. An approximate Hamiltonian is obtained which yields the perturbed energies (to first order) by the solution of a continued fraction similar to that employed for the rigid case. The result is applicable to any type of band and to any degree of asymmetry. With suitable additional restrictions it reduces to the semiclassical formulas of Cross[1] and of Lawrance and Strandberg.[2] Certain sum-rules for the rotational energy levels of semirigid molecules, analogous to those of Mecke for the rigid model, have been worked out. The methods for relating the centrifugal distortion coefficients to the force constants and geometry of the molecule have been somewhat simplified.

* Supported in part by ONR.
[1] P. C. Cross, Phys. Rev. **47**, 7 (1935).
[2] R. B. Lawrance and M. W. P. Strandberg, Phys. Rev. **83**, 363 (1951).

PA13. Density Matrix Formulation of LCAO Molecular Orbital Theory. WILLIAM J. TAYLOR, *Ohio State University*.—In the LCAO method, molecular orbitals, $\varphi_i(i=1,\cdots,n)$, are expressed in terms of atomic orbitals, $\chi_\alpha(\alpha=1,\cdots,\nu)$, as $\varphi_i=\Sigma_\alpha c_{\alpha i}\chi_\alpha$. Orthonormality of the φ_i's requires $\Sigma_{\alpha\beta}\bar{c}_{\alpha i}S_{\alpha\beta}c_{\beta j}=\delta_{ij}$, $S_{\alpha\beta}=\int\bar{\chi}_\alpha\chi_\beta dx$. Introduce the Dirac density matrix, $\rho(x,x')=\Sigma_i\varphi_i\bar{\varphi}_i'=\Sigma_{\alpha\beta}\rho_{\alpha\beta}\chi_\alpha\bar{\chi}_\beta'$, $\rho_{\alpha\beta}=\Sigma_i c_{\alpha i}\bar{c}_{\beta i}$. Define an LCAO "density matrix" $\boldsymbol{\rho}$, with elements $\rho_{\alpha\beta}$. The orthonormality condition yields $\rho^2=\int\rho(x,x'')\rho(x'',x')dx''=\rho$; similarly, $\Sigma_{\gamma\delta}\rho_{\alpha\gamma}S_{\gamma\delta}\rho_{\delta\beta}=\rho_{\alpha\beta}$, or $\boldsymbol{\rho}\mathbf{S}\boldsymbol{\rho}=\boldsymbol{\rho}$. Assume a $2n$-electron total wave function of the antisymmetrized *singlet* or *closed-shell* type. Then the total energy is $E=2\Sigma_iH_i+\Sigma_{ij}(2J_{ij}-K_{ij})$. H_i, is the one-electron nuclear-field energy; J_{ij} and K_{ij} are Coulomb and exchange integrals. Define the integrals, $H_{\alpha\beta}=\int\bar{\chi}_\alpha H\chi_\beta dx$, and $I_{\alpha\beta,\gamma\delta}=e^2\int\int\bar{\chi}_\alpha\chi_\beta r^{-1}\bar{\chi}_\gamma'\chi_\delta'dxdx'$, $r=|x-x'|$. Then $E=2\Sigma_{\alpha\beta}\rho_{\alpha\beta}H_{\beta\alpha}+\Sigma_{\alpha\beta\gamma\delta}\rho_{\alpha\beta}\rho_{\gamma\delta}(2I_{\beta\alpha,\delta\gamma}-I_{\beta\gamma,\delta\alpha})$. In principle, E can be minimized by variation of the $\rho_{\alpha\beta}$'s, subject to the auxiliary conditions stated. Roothaan has put Fock's self-consistent field equations in the form, $\mathbf{F}\mathbf{c}_i=\epsilon_i\mathbf{S}\mathbf{c}_i$; $\mathbf{c}_i=\{c_{1i},\cdots,c_{\nu i}\}$ is the ith eigenvector, and ϵ_i the ith eigenvalue. Roothaan's matrix $\mathbf{F}$ is expressed in terms of the $\rho_{\alpha\beta}$'s by $F_{\alpha\beta}=H_{\alpha\beta}+\Sigma_{\gamma\delta}\rho_{\gamma\delta}(2I_{\alpha\beta,\delta\gamma}-I_{\alpha\gamma,\delta\beta})$. If the $\rho_{\alpha\beta}$'s are guessed, one can compute $\mathbf{F}$, solve for the $\mathbf{c}_i$'s, recompute the $\rho_{\alpha\beta}$'s, etc. The total number of electrons is $2\int\rho(x,x)dx=2\Sigma_{\alpha\beta}\rho_{\alpha\beta}S_{\beta\alpha}=2n$. Thus $Q_\alpha=2e\rho_{\alpha\alpha}$ is the charge in the αth atomic orbital, and $P_{\alpha\beta}=2e(\rho_{\alpha\beta}\bar{S}_{\alpha\beta}+\bar{\rho}_{\alpha\beta}S_{\alpha\beta})$ is the charge in the $\alpha\beta$th "bond."

PA14. Modification of the Silberstein Model of Optical Anisotropy. FRANK MATOSSI, *U. S. Naval Ordnance Laboratory*.—The Silberstein model explains optical anisotropy (measured by Rayleigh scattering or Kerr effect) as caused by the interaction of induced dipoles. All applications of this model suffer from the fact that the numerical valuation yields atomic distances much too large. By correcting the dipole field, this discrepancy disappears without jeopardizing the applicability of the model to Raman effect and infrared spectrum. As in previous papers, the variation of the atomic polarizabilities must be taken into account. Numerical results will be presented for diatomic and symmetrical linear triatomic molecules.

PA15. A Phenomenological Model for the Excluded Volume Problem.[1] R. J. RUBIN[2] AND P. DEBYE, *Cornell University*.—The similarity in form between the path generated by a general random walk or diffusion process and the skeleton of a polymer molecule is complete if the nonzero excluded volume of the monomer units of the molecule is ignored. To take account of excluded volume, the phenomenological model assumed here is a diffusion model in which the direction of the Nth step in the diffusion process is influenced by the density δ of the previous steps, calculated ignoring excluded volume. The probability $\Phi(R_N-R_{N-1})$ for going from R_{N-1} to R_N is modified so that it has the form $\Phi(\Delta R)[1-v\delta(\Delta R,R_N)]$ where v is the excluded volume for a pair of steps. One is then led to a diffusion-like equation

$$\frac{\partial W}{\partial N}=-\beta\frac{R}{N}\frac{\partial W}{\partial R}+\frac{a^2}{6}\frac{1}{R^2}\frac{\partial}{\partial R}R^2\frac{\partial W}{\partial R}.$$

The solution of the equation of the form

$$W(N,R)=CN^{-\frac{3}{2}}\psi(3R^2/2Na^2)$$

involves confluent hypergeometric functions; and the mean square distance moved after N steps is $\langle R^2\rangle=Na^2/(1-5\beta)$.

[1] Supported by Office of Rubber Reserve.
[2] Now at The Applied Physics Laboratory, Johns Hopkins University, Silver Spring, Maryland.

Friday Afternoon at 2:30

Wardman Park, Continental Room

(R. R. Wilson presiding)

Reactions of Transmutation, II

Q1. The Excited States of F^{20} and O^{17}.* H. A. Watson, *M.I.T.*—The excited states of F^{20} have been investigated over a range of excitation energies from 0 to 5.1 Mev by magnetic analysis of the energy spectrum of protons from the $F^{19}(d, p)F^{20}$ reaction. Deuteron bombarding energies ranging from 1.5 to 2.1 Mev were used and observations taken at 90 degrees to the incident beam. Nineteen proton groups corresponding to the ground state and eighteen excited levels of F^{20} have been identified in the region investigated. Eight of the excitation energies calculated for the F^{20} levels are in good agreement with results recently obtained by Burrows, Powell, and Rotblat.[1] The energy spectrum of alpha-particles from the $F^{19}(d, \alpha)O^{17}$ reaction has also been analyzed. Alpha-particle groups corresponding to ten excited levels of O^{17} in the range of excitation energies from 0 to 6.9 Mev were found. Some of the groups corresponding to O^{17} levels of sufficient excitation to be unstable against neutron decay exhibited a broadening as a result of the natural width of the corresponding O^{17} levels. Widths ranging up to 35 kev are calculated for these levels.

* This work has been assisted by the joint program of the ONR and AEC.
[1] Burrows, Powell, and Rotblat, Proc. Roy. Soc. (London) **A209**, 461 (1951).

Q2. Neutrons from Deuterons on Neon (20).* C. P. Swann and C. E. Mandeville, *Bartol Research Foundation.*—A thin gaseous target of neon has been irradiated by deuterons of mean energy 1.0 Mev, supplied by the Bartol Van de Graaff statitron. The emitted neutrons were observed at angles of zero and 90° with the incident deuterons by the method of recoil protons in Eastman NTA plates. The reaction energy of $Ne^{20}(D, n)Na^{21}$ is measured to be (-0.17 ± 0.05) Mev as compared with a calculated Q value of $(+0.22\pm0.02)$ Mev. This computed value is based upon energy releases in reactions $Ne^{20}(D, p)Ne^{21}$, $Na^{21}(\beta+)Ne^{21}$, and $n^1(\beta-)H^1$, with the assumption that the positrons of Na^{21} proceed to the ground state of Ne^{21}. The disagreement between the calculated and observed Q values for $Ne^{20}(D, n)Na^{21}$ can be explained by either of two reasons: (1) The positrons of Na^{21} are coupled with gamma-rays of energy 0.39 ± 0.05 Mev. (2) The ground-state neutrons of $Ne^{20}(D, n)Na^{21}$ have not been observed in the present measurement.

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

Q3. Neutron Activation of Ne^{22} and N^{15}, and an Attempt to Detect Dineutrons in a Pile. A. J. Ferguson and J. H. Montague, *Chalk River Laboratories.*—A gas-flow method has been used to study the neutron activation of He, Ne, and N_2 at the surface of the reacting core in the N.R.X. pile. The activities were measured with thin-walled cylindrical Geiger counters surrounded by annular chambers through which the gas passed. Decay curves were obtained by varying the length of the flow path between the pile and the counters. The efficiency of the counting system was determined using the known cross sections[1] for the $Cl^{37}(n, \gamma)Cl^{38}$ reaction and the $O^{18}(n, \gamma)O^{19}$ reaction. For He no activation could be detected; this implies that the product of the dineutron flux, if present at all, and the cross section for the $He^4(n^2, \gamma)He^6$ reaction is less than 10^{-19} sec^{-1}. The cross section for $Ne^{22}(n, \gamma)Ne^{23}$ was determined as $(3.6\pm1.5)\times10^{-26}$ cm^2, and that for $N^{15}(n, \gamma)N^{16}$ as $(8.0\pm3.0)\times10^{-29}$ cm^2. It is believed that the nitrogen used was free of any contamination which could affect the above result for the N^{15} activation.

[1] Seren, Friedlander, and Turkel, Phys. Rev. **72**, 888 (1947).

Q4. Gamma-Rays from Na, Mg, and Al under Bombardment by 200–420 Kev Protons. Harvey Casson, *University of Chicago.*—Tangen[1] and others have found weak resonances for gamma-ray production in sodium, magnesium, and aluminum targets under bombardment of protons at energies below 420 kev. An investigation of the more prominent gamma-ray energies emitted at these resonances is being carried out with a NaI(Tl) crystal spectrometer. Since the gamma-ray yields are relatively low, some of the resolving power possible with the spectrometer is being sacrificed by bringing the crystal very near to a broad target. The spectrometer is calibrated in this geometry with 6.13-Mev gamma-rays obtained by bombardment of fluorine with 340-kev protons, and checked using Na^{22} and Co^{60} γ-ray sources. In the case of aluminum, the 404- and 325-kev resonances both show a 7.18 ± 0.07 and 1.80 ± 0.02-Mev γ-ray. Further numerical values of energies and relative intensities, with attempts at correlation with the known energy levels of these elements, will be presented.

[1] R. Tangen, Det Kgl Norske Videnskabers Selskabs Skrifter 1946, NRI (1947).

Q5. Energy Levels of Ti^{49}.* G. F. Pieper,† *Yale University.*—The proton groups from $Ti^{48}(d, p)Ti^{49}$ have been analyzed by measuring their ranges in aluminum at 90°. Targets were constructed from TiO_2 enriched to 98.9 percent Ti^{48}. At a mean deuteron energy of 3.79 Mev, 5 groups have been measured. The Q values obtained are 5.81, 4.41, 4.07, 3.36, and 2.67 Mev. The probable error in each value is approximately 50 kev. The value for the ground-state transition is in quite close agreement with that calculated from the packing fractions reported by Collins, Nier, and Johnson.[1]

* Assisted by the joint program of the ONR and AEC.
‡ AEC Predoctoral Fellow.
[1] Collins, Nier, and Johnson, Phys. Rev. **85**, 726(A) (1952).

Q6. Relative Yields of Bromine-80 Isomers in Nuclear Reactions.[1] Arthur W. Fairhall and Charles D. Coryell, *M.I.T.*—The isomeric pair 4.4h $Br^{80m}-18m$ Br^{80} has been made by a number of different nuclear reactions, (n, γ), (d, p), (p, n), $(d, 2n)$, (d, α), and (γ, n). The relative yield of the ground-state isomer to that of the metastable isomer is found to vary widely for different reactions, in a manner which shows the influence of the spin of the target nucleus, the orbital angular momentum and spin of the projectile, and the excitation energy involved in the nuclear reaction. For energies within 1 Mev of threshold for the (γ, n), (p, n), and $(d, 2n)$ reactions, the high spin metastable isomer is very weakly excited. The excitation curve for the $(d, 2n)$ reaction compared to the (p, n) reaction is not what one would expect of a stripping reaction unless the stripped proton carries into the nucleus more angular momentum than a corresponding free proton. In the (d, α) reaction, although high excitation energies are involved, the yield of metastable isomer is very low. This anomalous result may be explainable on the basis of emission of α-particles of low orbital angular momentum. Similar studies have been carried out on Zn^{69}, Se^{81}, In^{112}, and Te^{131}.

[1] Supported in part by the AEC.

Q7. The Reactions $Sr^{88}(d, p)Sr^{89}$, $Zr^{90}(d, p)Zr^{91}$, and $Mo^{92}(d,p)Mo^{93}$. F. B. Shull and C. E. McFarland, *Washington University*.*—Targets containing Sr in natural isotopic concentration and Zr^{90} and Mo^{92} in concentrated form[1] were bombarded with 10-Mev deuterons. Protons emitted at 90° to the incident beam were analyzed with respect to momentum by means of a 180° magnetic focusing charged-particle spectrometer, and were detected with nuclear emulsions. The preliminary Q values of the observed proton groups attributed to the residual nuclei, together with the corresponding nuclear excitation energies, are given in Table I. The range of momentum observed allowed the detection of proton groups corresponding to Q values from 1.56 to 5.26 Mev for Sr^{89}, from 1.23 to 6.29 Mev for Zr^{91}, and from 2.17 to 7.87 Mev for Mo^{93}. Other proton groups were observed but these were assigned to other nuclei present in the targets.

Table I.

Residual nucleus	Q values, Mev	Nuc. exc. energies, Mev
Sr^{89}	4.82, 3.70, 2.73, 2.31	0, 1.12, 2.09, 2.51
Zr^{91}	5.03, 2.93	0, 2.10
Mo^{93}	6.50, 4.91	0, 1.59

* Assisted by the joint program of the ONR and AEC.
[1] Electromagnetically concentrated isotopes supplied by Union Carbide and Carbon Corporation, Oak Ridge.

Q8. Nuclear Reactions in Cobalt and Arsenic. C. J. Avery, K. C. Kaericher, and M. L. Pool, *Ohio State University*.—6.3-Mev proton bombardment on Fe_2O_3 enriched* to 42.0 percent Fe^{58} produced the 8.8-hour Co^{58} activity. The half-life was found to be $9.0 \pm .2$ hours. Aluminum absorption measurements showed the presence of electrons of 0.0185 Mev. The x-rays emitted by the 9-hour activity proved to be characteristic of Co and those emitted by the 72-day activity characteristic of Fe. The relative cross sections for the 72-day Co^{58} activity, the 80-day Co^{56} activity, and the 9-hour Co^{58} activity proved to be 8:0.6:1. The above activities are thus strongly genetically related. Bombardment of natural Ge and Ge^{70} enriched to 88.1 percent failed to produce the reported 52-minute activity. The relative cross sections for the reactions $Ge^{70}(p, \gamma)$, $Ge^{72}(p, n)$, $Ge^{73}(p, \gamma)$, and $Ge^{74}(p, n)$ are approximately 1, 14.7, 0, and 8.3, respectively.

* Supplied by Y-12 plant, through the Isotopes Division, Oak Ridge.

Q9. (α, n) and (α, $2n$) Cross Sections with Ag^{109}.* E. Bleuler and D. J. Tendam, *Purdue University*.—By applying the statistical theory of nuclear reactions to the excitation curves of (α, n) and (α, $2n$) reactions with Rh and Ag, Bradt and Tendam[1] found for the nuclear temperatures involved a value of about 1.8 Mev, at around 10-Mev excitation energy. Since direct measurements of the neutron energy distribution[2] and theoretical estimates yield somewhat lower values, the excitation curves have been remeasured with enriched Ag^{109}.[3] Absolute cross sections have been obtained by coincidence and spectrometer methods. If the neutron energy distribution $N(E) = \text{const}\ E \exp(-E/T)$ is assumed, one obtains nuclear temperatures which increase from about 1.2 Mev near the threshold of the (α, $2n$) reaction (14.8 Mev) to 1.7 Mev at 4 Mev above threshold. The total cross section for alpha-particles, taken as $\sigma(\alpha, n)+\sigma(\alpha, 2n)$, indicates a nuclear radius ($R=r_0A^{\frac{1}{3}}$) corresponding to a value of r_0 slightly larger than 1.4×10^{-13} cm.

* Supported by the AEC.
[1] H. L. Bradt and D. J. Tendam, Phys. Rev. **72**, 1117 (1947).
[2] P. C. Gugelot, Phys. Rev. **81**, 51 (1951).
[3] Obtained from the Isotopes Division of the AEC, Oak Ridge.

Q10. Proton Groups from the Deuteron Bombardment of Co^{59} and Cu^{63}. Donald C. Hoesterey, *Yale University*.—Proton groups from nuclear energy levels have been obtained at 90° with respect to the incident beam from the reactions $Co^{59}(dp)Co^{60}$ and $Cu^{63}(dp)Cu^{64}$ using 3.80-Mev deuterons from the Yale University cyclotron. Q values for the ground and first excited states of Co^{60} are, respectively, 5.30 Mev and 4.86 Mev. Levels with Q values of 5.66 Mev, 5.15 Mev, and 4.37 Mev, for the ground, first, and second excited states respectively were obtained from the bombardment of an enriched Cu^{63} target. A highly biased proportional counter was used to detect only the protons whose paths ended in the counter. The energy of the emitted protons was measured by interposing aluminum absorbers between the target and counter.

Friday Afternoon at 2:15

Shoreham, Terrace Room

(J. H. Van Vleck presiding)

Invited Papers

R1. A Cosmic-Ray Experiment on the Inelastic Cross Sections of Hydrogen and Other Nuclei for Pions. O. Piccioni and R. L. Cool, *Brookhaven National Laboratory*. (30 min.)

R2. High Pressure Diffusion Cloud Chambers and Their Applications, with Results of Scattering of Pions by Light Nuclei. R. P. Shutt, *Brookhaven National Laboratory*. (30 min.)

R3. Recent and Prospective Improvements in Measurement of Nuclear Energy-Levels. J. W. M. DuMond, *California Institute of Technology*. (45 min.)

Friday Afternoon at 2:15

Wardman Park, Burgundy Room

(E. Fermi presiding)

Meson-Theory; Nuclear Shell-Structure

RA1. Phenomenological Potentials in Meson Scattering. R. LeLevier, *University of California, Berkeley*.—The experimental data on elastic scattering of 62- and 90-Mev pions by carbon contain two significant features: (1) There is a large amount of large angle scattering; (2) at small angles, where Coulomb interference is important, π^+ is less than π^- scattering. One cannot fit the data over the entire angular range by means of a conventional attractive potential[1] since destructive interference between P-wave scattering and S- and D-wave scattering would result in a small cross section at the large angles. A potential which is entirely repulsive in character is unsatisfactory for the same reason. Furthermore, the π^- scattering would be greater than π^+ scattering at small angles because of Coulomb interference. However, if one adds to an attractive potential a central region of repulsion the P-wave phase shift is greatly reduced, the D-wave phase shift is essentially unaltered and the scattering exhibits features (1) and (2) mentioned above. A potential of this form is motivated by Schiff's nonlinear meson theories.[2] The scattering by such potentials is of course extremely parameter sensitive and the fit with experiment is still only qualitative.

[1] D. C. Peaslee, "Coulomb Effects in Meson Scattering," CR-1713, Columbia University, December 7, 1950.
[2] L. I. Schiff, Phys. Rev. **84**, 1, 10 (1951).

RA2. Angular Distribution of π-Carbon Scattering.* D. C. Peaslee, *Columbia University*.—An average angular distribution for π-nucleon scattering of the form $f(\theta)=(\alpha+\beta\cos\theta+3\cos^2\theta)/(\alpha+1)$ is inferred from elastic π-carbon scattering at 60 Mev[1] by means of a Born approximation and independent-nucleon wave functions. If $\hbar k$ is the meson momentum and $K=2k\sin\theta/2$, carbon scattering is proportional to $\theta(\theta)|\rho(K)|^2$, where $\rho(K)$ is the average Fourier component of the single-nucleon density, and to a good approximation $f(\theta)$ behaves like an intrinsic nucleon form factor with coefficients α, β dependent only on k and not on K. The shape necessary for ρ indicates that individual nucleons are localized to roughly α-particle volumes. The "best" (±50 percent) values for the parameters are $\alpha\sim1/3$, $\beta\sim-1$, indicating that (1) meson-nucleon scattering is predominantly p-wave; (2) the ratio of p-scattering with nucleon spin flip to scattering without spin flip is $\lesssim1/5$; (3) some s-wave interference appears to be present, with $|\delta_s-\delta_p-\pi/2|\lesssim\pi/3$. The total s-wave scattering is $\lesssim10$ percent of the total p-wave scattering. The values of α and β do not apply to free-nucleon scattering because of the exclusion principle.

* This work is supported by the research program of the AEC.
[1] Byfield, Kessler, and Lederman, Phys. Rev. (to be published).

RA3. Surface Production of Charged Mesons by Photons on Nuclei. S. T. Butler, *Cornell University* (*Introduced by* R. R. Wilson).—An estimate has been made of the magnitude of the photoproduction cross section of charged mesons from "surface nucleons," i.e., the weakly interacting nucleons which make up the less dense nucleon atmosphere surrounding the main body of a nucleus. It is found that, quite apart from having the correct $A^{2/3}$ dependence for the $\pi^++\pi^-$ cross section, the surface effect can account for considerable fractions ($\gtrsim50$ percent) of the observed yields[1] (allowance being made for meson absorption by the residual nuclei), and because of the differences in average binding between neutrons and protons in nuclei, gives π^-/π^+ ratios which vary in good agreement with the experimental variations. The results suggest that the production of mesons from the core of a nucleus is somewhat suppressed (apart from the ordinary binding energy reduction). A possible explanation is that an intermediate excited state of a nucleon which is strongly interacting with one or more neighbors can decay, not only by photon or meson emission, but also to an appreciable extent by a disintegration of the interacting nucleon group.[2]

[1] R. M. Littauer and D. Walker, Phys. Rev. **83**, 206 (1951).
[2] R. R. Wilson, Phys. Rev. **86**, 563 (1952).

RA4. Meson Production by Nucleons in Coulomb Fields.* E. D. Courant, *Brookhaven National Laboratory*.—When a nucleon passes through the Coulomb field of a nucleus mesons may be produced by virtue of the charge of the nucleon, the magnetic moment of the nucleon, or the charge of the meson. The cross section for this process has been obtained, using the pseudoscalar meson theory with pseudovector coupling and treating the nucleon magnetic moments by means of a Pauli term.[1] The cross section increases with the fourth power of the nucleon energy, due to the finite size of the nucleus, up to an energy of about $(\mu cR/\hbar)$ Mc^2, and then levels off with increasing nucleon energy. For 3-Bev protons on lead, the differential cross section for the production of 500-Mev positive mesons in the forward direction is about one millibarn per steradian per Bev.

* This work was performed under the auspices of the AEC.
[1] M. F. Kaplon, Phys. Rev. **83**, 712 (1951).

RA5. Multiple Meson Production. M. Ruderman, *University of California, Berkeley*.—The solution of the equation of motion of the nucleon spin[1] in the presence of a strong transient external force indicates that, for a sufficiently energetic interaction, most of the transferred energy goes into kinetic energy of spin rotation (isobar excitation) rather than into immediate meson emission. The isobar subsequently decays to the ground state with multiple emission. If, following Fermi,[2] it is assumed that in a very high energy collision the collision products are determined by their statistical weights, the possibility of isobar production should therefore be included. For center-of-mass energy $W\ll100$ Mc^2 they have little effect. At higher energies they dominate because of their high spin and charge degeneracy. Taking for the isobar level separation the results of symmetrical pseudoscalar meson theory fitted to give a first excited state at ~300 Mev, the meson multiplicity is $\sim0.65(W/\text{Mc}^2)^{9/11}$. The ratio of antiprotons to mesons is $(0.07)\exp(-2\,\text{Mc}^2/kT)(\text{Mc}^2/kT)^{1/2}$, and $(kT/\text{Mc}^2)\sim(W/\text{Mc}^2)^{4/11}\,(0.12)\gg1$. The inclusion of isobars keeps this ratio small with a maximum near $kT/\text{Mc}^2\sim1$.

[1] W. Pauli, *Meson Theory of Nuclear Forces* (Interscience Publishers, Inc., New York, 1948).
[2] E. Fermi, Prog. Theoret. Phys. **5**, 570 (1950).

RA6. On the Decay of a Scalar Particle into Three Photons. L. Wolfenstein and G. D. Ravenhall, *Carnegie Institute of Technology*.—By means of an explicit construction, it may be shown that the decay of a scalar (or pseudoscalar) neutral particle into three photons is consistent with the conditions of invariance under rotations and reflections. On the other hand, the matrix element for the decay of singlet positronium into three photons is zero to first order, and for all the interactions we have been able to think of the decay of a scalar meson into three photons is forbidden (to all orders) by Furry's theorem. This suggests strongly that there exists a further invariance principle yielding a selection rule for this case. The selection rules arising from the following well-known invariance principle are therefore being investigtted: The theory is invariant under the transformation in which all charged fields are transformed to their charge conjugate fields and the electromagnetic field is reversed in sign. Under this transformation the matrix element between the singlet state of an electron and positron at rest and a state of three photons changes sign, which shows that this matrix element must vanish to all orders. Further results will be discussed.

RA7. Strong Coupling in Relativistic Meson Theory. MURRAY GELL-MANN AND MARVIN L. GOLDBERGER, *University of Chicago.*—The problem of a nucleon interacting with a meson field is treated according to the approximation in which "closed-loop" Feynman diagrams are omitted, though nucleon recoil and virtual nucleon pairs are otherwise taken into account. The equations relating the Feynman amplitudes describing the presence of various numbers of virtual mesons are shown to be equivalent to an eigenvalue equation similar to that encountered in the "one-particle" Dirac theory of a nucleon and a quantized field. It is found that in this form the problem can be attacked by strong-coupling methods. In particular, the case of pseudoscalar meson theory with strong pseudoscalar interaction will be discussed.

RA8. Nuclear Structure and Interpretation of β-Decay.* R. KING AND E. FEENBERG, *Washington University.*—The nuclear shell model and the ft product of β-decay correlate the character of the β-transitions with the spin and parity of the nuclear levels. When a histogram of the ft products is made for even A transitions between ground states, one expects by Nordheim's rules to have the group $\Delta I=0$ (no) transitions absent, and this shows itself by the lack of a peak at $\log ft\sim 5.5$ which does occur for even A transitions to excited states, and also for odd A transitions. By assigning spins and parity from the shell model for odd A nuclei, one can locate the group $\Delta I=0$ (yes) transitions. The range indicated is $\log ft\sim 6.0$ to 6.9, that is, above $\log ft\sim 6.9$ both $\Delta I=\pm 1$ (yes) and $\Delta I=0$ (yes) are present. This proves consistent with the grouping of even A transitions between ground states, where the few found in this range can be interpreted as $\Delta I=0$ (yes) transitions. Possible explanations will be discussed.

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

RA9. Ground-State Spins and Energy Differences from the *jj*-Coupling Model.* D. KURATH, *Argonne National Laboratory.*—The order of energy levels for configurations of jj-coupled nucleons is investigated. Calculations for $1p$, $1d$, and $1f$ nucleons use oscillator functions for the individual particles and a central interaction with Gaussian range dependence between nucleons. In the limit of vanishing interaction range the conclusions are as follows:

	Configuration	Ground state
(1)	$(j)^{2n}$, identical nucleons	$J=0$; order is 0, 2, 4
(2)	$(j)^{2n+1}$, identical nucleons	$J=j$
(3)	$(j)^{2n+1}$, mixed nucleons	$J=j$
(4)	$(j_1)^1(j_2)^1$ neutron-proton	$J=\|j_1-j_2\|$
(5)	$(j_1)^1(j_2)^{-1}$ neutron-proton	$J=j_1+j_2-1.$

Configuration (5) is that of K^{40} and Cl^{36}. Use of finite range interaction brings other levels into consideration, but (1), (3) and to a lesser extent (2), (5) are likely to remain unchanged. For (4), $J=j_1+j_2$ becomes more likely. For odd-A beta-decays in the $1/f_{7/2}$ shell, the binding energy differences, exclusive of the Coulomb contribution, show better agreement with the jj-coupling model than with the weak spin-orbit coupling model.

* Work done in part at the University of Chicago.

RA10. Excited States of Even-Even Nuclei. GERTRUDE SCHARFF-GOLDHABER, *Brookhaven National Laboratory.**—A general survey of excited states of even-even nuclei yielded the following results: The nth excited state has usually a spin $I\leq 2n$. For $n=1$, $I=2$ (even parity) with few exceptions.[1,2] The energy of the first excited state plotted against the number of protons or neutrons in the nucleus reaches maxima at closed shells. Wherever the first excited state is very low, e.g., in the rare earths region and in the heavy elements from thorium up, the one particle model for odd A nuclei is likely to break down except for the ground state. The lack of isomers for odd proton nuclei below magic number 82 may be due to this fact. The average energy of the first excited state of the even-even core in this region is of the order of 0.1 Mev, whereas the energy of the core of the corresponding odd neutron nuclei ($N<82$) is of the order of 0.5 Mev. The approximately predictable position of the first excited state may have many applications (e.g., inelastic scattering of nucleons).

* Under contract with the AEC.
1 M. Goldhaber and A. W. Sunyar, Phys. Rev. **83**, 906 (1951).
2 Horie, Umezawa, Yamaguchi, and Yoshida, Prog. Theoret. Phys. **6**, 254 (1951).

RA11. Surface Energy in the Free-Particle Nuclear Model.* K. C. HAMMACK AND E. FEENBERG, *Washington University.*—The kinetic energy of Λ noninteracting particles in a box-shaped potential well of infinite depth and dimensions L_1, L_2, L_3 is found as a series with terms proportional to Λ, $\Lambda^{2/3}$, $\Lambda^{1/3}$, $\cdots$, and with coefficients involving the volume, surface area, and "characteristic length" $(L_1+L_2+L_3)$ of the box. The fact that the leading term, or volume energy, is derivable from Fermi-Dirac statistics for a volume of arbitrary shape makes reasonable the assumption that also the surface term is applicable to a region of any shape, and in particular to a sphere. Further calculations extend the method to wells of finite depth and to particles in all four charge-spin states. One then obtains the total energy for a nuclear model consisting of A noninteracting nucleons in a spherical potential well of finite, constant depth, expressed as a series in A, $A^{2/3}$, $A^{1/3}$, $\cdots$. The $A^{2/3}$ term indicates a surface energy about two-thirds as large as empirical mass and fission data require. The $A^{1/3}$ term has no apparent physical meaning, but is quite small. Its evaluation involves an attempt at a definition of the "characteristic length" of a region of arbitrary shape.

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

FRIDAY EVENING AT 7:00

Shoreham

(J. H. VAN VLECK presiding)

Banquet of the American Physical Society

After-dinner speakers: E. M. MCMILLAN, S. A. GOUDSMIT, AND J. E. MAYER

SATURDAY MORNING AT 9:30

Shoreham, West Ballroom

(B. J. MOYER presiding)

Mesons; Neutron-Electron Interaction

S1. Gamma-Radiation Associated with the Stopping of μ⁻ Mesons in Lead.* A. FAFARMAN AND M. H. SHAMOS, *New York University.*—We wish to report on some preliminary results of an experiment designed to study the gamma-radiation[1] associated with the stopping of μ^- mesons in absorbers of high and intermediate Z. The gamma-ray pulse heights are recorded by a NaI(Tl) scintillation spectrometer "C" (surrounded by anticoincidence G-M counters X_1). Cosmic-ray mesons stopping in the absorber are selected by a counter telescope (AB) with 10-cm Pb filter and with anti-coincidence G-M counters X_2 beneath the absorber. The resolving time for ABC coincidences at present is 0.9 μsec. The (ABC−X) counting rate with Pb absorber is 0.25±.04/hr, while the counting rate with no absorber is 0.09±.03/hr. At present, the minimum pulse height which the spectrometer records corresponds to an energy loss of ~1.5 Mev in the NaI(Tl) crystal. Measurements are being made with Pb and Fe absorbers and with the spectrometer adjusted to record smaller pulse heights. The spectra and energies will be discussed in relation to mesonic Bohr orbit transitions.[2]

* Supported by the AEC.
[1] W. Y. Chang, Revs. Modern Phys. **21**, 166 (1949).
[2] J. A. Wheeler, Revs. Modern Phys. **21**, 133 (1949).

S2. Range Distribution of μ-Mesons from π-Meson Decays in Photographic Emulsions.* GEORGE R. WHITE, *Iowa State College,* AND W. F. FRY,† *Iowa State College and the University of Chicago.*—The lengths of μ-meson tracks from 530 π-meson decays have been measured in one Ilford C-2 200 micron emulsion, which had been exposed in a spiral orbit spectrometer to the Berkeley cyclotron.[1] The random experimental error in the measurement of the track lengths has been found to be less than 1 percent by repeated measurements of the same tracks. The range distribution of the μ-mesons appears to be Gaussian, with a standard deviation of 30 microns. This width is not inconsistent with the standard deviation expected from straggling. The data indicate that the main body of the range distribution is symmetrical. The mean length of the μ-meson tracks is 598 microns. The probability of soft photon emission accompanying π-meson decay[2] is expected to be too small to affect the distribution curve for so few events. Possible corrections due to the thickness of the emulsion compared to the range of the μ-mesons, decay in flight of the π-mesons, and the vertical shrinkage of the emulsion have been considered.

* Supported in part by a grant from the Research Corporation.
† AEC Postdoctoral Fellow.
[1] R. Sagane and P. C. Giles, Phys. Rev. **81**, 653 (1951).
[2] H. Primakoff, Phys. Rev. **84**, 1255 (1951); T. Eguchi, Phys. Rev. (to be published); Nakano, Nishimura, and Yamaguchi, private communication.

S3. Photo Production of π⁰-Mesons from Deuterium. W. HECKROTTE, L. R. HENRICH, AND J. V. LEPORE, *University of California, Berkeley.*—Previously reported calculations[1] have been extended to include the total cross section for the photo production of π^0-mesons from deuterium. It was pointed out that, because of interference effects, the experimental ratio of the deuterium cross section to that of hydrogen could lead to a determination of the relative signs of the neutral meson coupling constant for protons and neutrons. When the final state of the two nucleons is a deuteron, the ratio of total cross sections for $g_p=-g_n$ to that for $g_p=g_n$ is about 28. When the unbound states of the two nucleons are included, this ratio is only about 2.6 in the region immediately above threshold. This change is brought about by the relatively large singlet state contribution which is proportional to $(g_p\mu_p-g_n\mu_n)^2$, thus increasing the contribution for $g_p=g_n$. However, if one looks at the π^0-mesons at 90° only, this ratio is increased to 17. The values of the deuterium to hydrogen total cross sections are 2.6 for $g_p=-g_n$ and 0.9 for $g_p=g_n$. The experimental value for much higher gamma-ray energies is 1.94.[2] The results of the calculation for higher energies will be reported.

[1] Heckrotte, Henrich, and Lepore, Phys. Rev. **85**, 490 (1952).
[2] Silverman and Cocconi, Bull. Am. Phys. Soc. **27**, No. 1, 27 (1952).

S4. The Excitation Function for π⁺ Mesons Produced in P−P Collisions. A. G. SCHULZ, D. HAMLIN, M. J. JAKOBSON, AND J. MERRITT, *University of California, Berkeley.*—The relative cross sections at one angle for the reaction $p+p\rightarrow\pi^+ +d$ have been measured[1,2] using the external proton beam of the Berkeley synchrocyclotron. The π^+ mesons produced at 0°±5° to the beam direction are magnetically separated from the proton beam and detected by scintillation counters using a delayed coincidence between the π^+ and its μ^+ decay.[3] A polyethylene-carbon difference is used to obtain the hydrogen contribution. In order to obtain protons of various energies below 340 Mev, lead absorbers are placed in the proton beam immediately ahead of the polyethylene and carbon targets. The π^+ contribution from the lead absorbers is automatically subtracted with the carbon contribution. At each proton energy the π^+ energy spectrum is scanned in the region of the characteristic peak attributed to the reaction given above and the relative $d\sigma/d\Omega$ is obtained by integrating over meson energy. The data obtained thus far agrees with an $E^{\frac{3}{2}}$ curve, where E is the meson kinetic energy in the center of mass system. The data joins smoothly with the data for higher proton energies is obtained from the inverse experiment and detailed balancing.[4]

[1] Cartwright, Richman, Whitehead, and Wilcox, Phys. Rev. **78**, 823 (1950) and Phys. Rev. **81**, 652 (1951).
[2] Crawford, Crowe, and Stevenson, Phys. Rev. **82**, 97 (1951).
[3] Jakobson, Schulz, and Steinberger, Phys. Rev. **81**, 894 (1951).
[4] Durbin, Loar, and Steinberger, Phys. Rev. **84**, 581 (1951).

S5. Unusual π−μ Decays in Photographic Emulsions.* W. F. FRY,† *University of Chicago.*—A search has been made for unusual $\pi-\mu$ decays in C-2 and G-5 plates which had been exposed to the Berkeley and Chicago cyclotrons. Thirteen decays have been found with abnormal μ-meson ranges among 10,686 normal decays. The ranges in microns of the thirteen μ-tracks are as follows: 975, 828, 476, 444, 260, 258, 470, 441, 430, 416, 290, 185, and 120. The unusual ranges of the μ-mesons of the first six events can be explained by decay in flight of the π-mesons. The grain density along the π-tracks and the angles between the π- and μ-tracks in the last events are inconsistent with the assumption of decay in flight of the π-mesons. Correcting for the thickness of the emulsions, the ratio of unusual to normal events is $2.8\pm1.2\times10^{-4}$ excluding events which can be decays in flight. The percentage of unusual events and the energy distribution of the μ-mesons are in general agreement with the assumption of soft photon emission accompanying the decay. Short μ-meson tracks from π-decays have also been found by others.

* Supported by a joint program of the ONR and AEC. The initial work was undertaken at Iowa State College and supported by a grant from the Research Corporation.
† AEC Postdoctoral Fellow.

S6. π^0 Meson Production by 430-Mev Protons on Beryllium.* L. MARSHALL, J. MARSHALL, V. A. NEDZEL, AND S. WARSHAW, *University of Chicago*.—π^0 decay gamma-rays were observed through a nearrow lead collimator in the forward direction from a beryllium target bombarded by the 450-Mev maximum energy internal proton beam of the 170-inch synchrocyclotron. The π^0 production cross section was measured both by means of a round pole pair spectrometer and by direct observation with a water-Čerenkov counter of the pairs produced in a lead radiator. The proton beam intensity at the beryllium target was measured by the heating of the target. The differential photon production cross section was measured to be 3.4×10^{-27} cm²/sterad with the pair spectrometer and 4.26×10^{-27} cm²/sterad with the Čerenkov telescope, from which one computes the π^0 cross section as 4.9×10^{-27} cm² and $6.7\pm1.5\times10^{-27}$ cm², respectively. The pair spectrometer value is subject to errors in the cross section which may be as large as 50 percent because of uncertainties in the calculated efficiency of the round pole spectrometer, a function which varies rapidly with photon energy and geometry.

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

S7. π^0 Meson Production by 430-Mev Protons on Hydrogen.* J. MARSHALL, L. MARSHALL, V. A. NEDZEL, AND S. WARSHAW, *University of Chicago*.—An internal liquid hydrogen target was bombarded with 450-Mev maximum energy protons with the 170-inch synchrocyclotron. Scattering from the median plane was used to deflect protons to the inside of the target and a collimator was so placed as to accept gamma-rays within a small solid angle in the forward direction from a definite area of the thin end windows of the target. A lead radiator—water Čerenkov counter detector was used, as in the previous abstract, to count the gammas. Proton currents were measured by radioactivation of aluminum foils. The differential photon production cross section was measured to be 0.21×10^{-27} cm²/sterad. The π^0 production cross section is $0.30\pm0.08\times10^{-27}$ cm². There is a possibility that a part of the measured cross section may be due to gamma-rays produced by the capture of stray π^- mesons in the hydrogen. We believe the contribution from this source to be small but are engaged in a series of experiments to measure the size of the effect. The cross section given above should be considered as tentative until these experiments have been performed.

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

S8. Elastic Scatting of Pions from Hydrogen and Deuterium.* GERSON GOLDHABER, *Columbia University*.—Elastic scattering events of 70-Mev π^+ and π^- mesons from hydrogen and deuterium were observed in photographic emulsions. The elastic scattering events, which are characterized by (1) co-planarity, (2) angular correlation, and (3) range of scattered particle (proton or deuteron, respectively) were observed in area scanning of the nuclear emulsions. Normal Ilford G5 emulsions as well as H_2O and D_2O loaded emulsions were used. The emulsions were exposed to the pion beams to the Nevis synchrocyclotron. The scanning of these plates is still in progress and preliminary results are presented in Table I.

TABLE I. Elastic scattering events with 70-Mev pions.

Elastic scattering	Total path g/cm²	No. of events[a]	No. of probable events[b]	Cross section[c] mb
π^++H	330± 50 (hydrogen)	4	3	35±15
π^-+H	630±100 (hydrogen)	0	1	2.5
π^-+D	400±100 (deuterium)	2	0	17

[a] Events satisfying conditions 1, 2, and 3.
[b] Events satisfying conditions 1 and 2 with recoil particles leaving emulsion.
[c] Probable events were counted as events in this cross-section estimate.

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

S9. Neutrons from Capture of Slow Negative π-Mesons.* V. COCCONI TONGIORGI AND DONALD A. EDWARDS, *Cornell University*.—Measurements have been performed of the number of neutrons of moderate energies (0.5 to 10 Mev) emitted by a nucleus in which a slow negative π-meson has been captured. The mesons (40 to 70 Mev) were produced by the 310-Mev bremsstrahlung radiation of the Cornell synchrotron impinging on a Be-target. The negative mesons were selected by double focusing magnets and stopped in absorbers of different Z. The neutrons were slowed down in paraffin and recorded by BF_3 counters. The data so far available indicate that for every π-meson captured in a Pb-nucleus, $\sim$7 neutrons with energies smaller than 10 Mev are produced on the average. In carbon the multiplicity of such neutrons is $\sim$1. These data support the interpretation that the starless π-meson tracks observed in photographic emulsions are associated with emission of neutrons only. The high neutron multiplicity observed for Pb confirms that the excitation energy given to the nucleus by a π-meson is much larger than that given by a π-meson ($\bar{\nu}_\mu\simeq2$). The very low multiplicity of the neutrons recorded from carbon probably indicates that some of the neutrons emitted have energies too high to be recorded.

* Supported by the ONR.

S10. The Neutron-Electron Interaction.* J. A. HARVEY, D. J. HUGHES, AND M. D. GOLDBERG, *Brookhaven National Laboratory*.—The electrostatic neutron-electron interaction, caused by the dissociation of the neutron into a proton and a meson, has been measured by a mirror experiment. A well-collimated beam of neutrons was totally internally reflected from a bismuth mirror covered with liquid oxygen. From the critical angle for total reflection for graphite filtered neutrons and the coherent scattering amplitudes of bismuth and oxygen we determine the neutron-electron interaction. The liquid oxygen is used since it balances the nuclear scattering of bismuth almost completely, with the result that the critical angle is very sensitive to neutron-electron scattering. The free atom cross sections of bismuth and liquid oxygen were determined from transmission measurements with pile neutrons filtered through various thicknesses of cadmium and boron. Since the incoherent scattering cross sections of bismuth and oxygen are small, the coherent amplitudes follow directly from the free atom cross sections. The neutron-electron interaction can be represented by a potential well equal to the radius of electron and a depth only a few hundred volts greater than the magnetic interaction of 3900 volts. This difference, which is the electrostatic interaction between the neutron and the electron, is smaller than the predictions of meson theory.

* Research carried out under contract with the AEC.

Invited Paper

S11. Characteristics of Neutral Meson Production in Nucleon Collisions. B. J. MOYER, *University of California, Berkeley*. (40 min.)

Saturday Morning at 9:30

NBS, Materials and Testing

(P. H. Miller presiding)

Invited Papers on Semi-Conductors and Silicon

SA1. Surface Properties of Germanium. W. H. Brattain, *Bell Telephone Laboratories.* (40 min.)

SA2. Magnetism Due to Current Carriers and to Impurities in Semi-Conductors. G. Busch, *Swiss Institute of Technology.* (40 min.)

SA3. Germanium and Silicon Single Crystals. G. K. Teal, *Bell Telephone Laboratories.* (40 min.)

Saturday Morning at 9:30

NBS, East Building Lecture Room

(J. B. Fisk presiding)

Entropy and Information

T1. Entropy and Information. B. McMillan, *Bell Telephone Laboratories.* (45 min.)

T2. Quantal and Non-Quantal Uncertainties. N. Wiener, *M.I.T.* (40 min.)

T3. The Negentropy Principle of Information. L. Brillouin, *Watson Laboratories of I.B.M.* (30 min.)

Saturday Morning at 10:00

Wardman Park, Continental Room

(F. Rasetti presiding)

Neutron-Capture

U1. Total Cross Sections for High Energy Neutrons. Vaughn Culler and R. W. Waniek, *Harvard University.*—The total nuclear cross sections of carbon and hydrogen have been measured in good geometry with the neutron beam produced from a ¼-in. beryllium target bombarded with 110-Mev protons of the Harvard 95-in. synchrocyclotron. The collimated neutron beam was first monitored by a scintillation counter telescope in triple coincidence and then passed through the absorber samples of the element under study. The attenuated beam went through a second collimator and impinged on a polyethylene scatterer. A five-crystal scintillation counter telescope arranged at 15° detected the scattered protons. By examining double, triple, fourfold, and fivefold coincidences, cross sections have been determined simultaneously for four energy bands.

U2. Preliminary Investigations of Neutron Total Cross Sections with the Oak Ridge National Laboratory Fast Chopper. G. S. Pawlicki* and E. C. Smith, *Oak Ridge National Laboratory.*—A neutron time of flight spectrometer has been operated at a resolution of 1.2 μ-sec/meter. The opaque zone of the shutter is formed by laminated plastic, with the slots defined by monel metal. The detector is a 1-atmosphere single BF_3 pulse ion chamber with a length of 12 inches and frontal area of 24 square inches. An 84-channel time-gated counting circuit is employed. The transmission of indium has been scanned down to 1 ev. Five resonances above 10 ev have been observed. Isotopic assignment is currently in progress.

* Catholic University, ORINS Fellow.

U3. Cross Section of Fe for Cold Neutrons.* H. Palevsky and D. J. Hughes, *Brookhaven National Laboratory,* and R. R. Smith, *Columbia University.*—The neutron cross section of Fe has been measured in the region between 4–14A with the Brookhaven Slow Chopper, at sample temperatures of 150, 295, and 450°K. The measured cross section is $\sigma = a + [b + c(T)]\lambda$, that is, a constant (incoherent isotope scattering) and a term proportional to wavelength (nuclear capture plus inelastic scattering). The cross section curves for various temperatures T give 0.42±0.02 barn for "a," in exact agreement with the isotope-incoherent scattering calculated from the measured isotopic cross sections.[1] The temperature dependent part of the cross section was found to be in good agreement with the calculations of Kleinman for the inelastic scattering of neutrons by crystals. The temperature independent part of the wavelength proportional term was found to be slightly larger than reported values of capture in iron. No. (100) reflection was found, even at low temperatures, as might be expected from the antiferromagnetic structure postulated by Zener.

* Research carried out under contract with the AEC.
[1] Shull, Wollan, and Koehler, Phys. Rev. **84**, 912 (1951).

U4. Measurement of Total Neutron Cross Sections at Energies Between 3 and 12 Mev.* N. Nereson, *Los Alamos Scientific Laboratory.*—Total cross sections are measured as a function of neutron energy in the continuous spectrum of the neutron beam emerging from the Los Alamos fast reactor by using a neutron spectrometer as a detector. The spectrometer consists of a parallel plate ionization chamber in which the energies of collimated recoil protons from a hydrogenous radiator are determined. A small proportional counter between the radiator and the chamber helps to identify the desired recoils and thereby to reduce background. An energy resolution of better than 10 percent has been achieved in the range of neutron energies from 2.5 to 12 Mev. The method has been tested by checking the exponential attenuation of neutron intensity in samples of various thicknesses and by measuring the (n, p) cross section at energies from 3 to 10 Mev. A comparison with better resolution measurements was carried out by measuring the cross sections of Be and C from 2.5 to 6 Mev. A peak in the cross section of C was found at about 8 Mev. The method should be useful for surveys of total cross sections at energies not readily accessible with sources giving neutrons of variable energy.

* Work performed under the auspices of the AEC.

U5. Level Densities from Fast Neutron Capture.* R. C. GARTH, D. J. HUGHES, AND J. S. LEVIN, *Brookhaven National Laboratory*.—The level density w in the compound nucleus can be calculated from the capture cross section for fast neutrons (1 Mev, where $\Gamma n > \Gamma\gamma$) if the radiation width $\Gamma\gamma$ is known: $\sigma = 2\pi^2\lambda\!\!\!^{-2}\Gamma\gamma w$. Using the radiation width estimated by Heidmann and Bethe,[1] the fast cross sections previously reported,[2] and experimental neutron binding energies, the level density has been calculated for a number of nuclei at excitation energies about 8 Mev. The resulting level densities compare well with the statistical nuclear model for nonmagic nuclei. Neutron-magic nuclei, however, show a level spacing definitely larger than expected from the statistical model, even after correction for the difference (about 2 Mev) in excitation energy. Cross sections of the proton-magic tin isotopes are now being measured. The thermal cross section for formation of the 10-minute Sn^{125} is about one-third the reported values, and preliminary results for the fast cross sections of several tin activities are in the 10–15 millibarn range.

* Research carried out under contract with the AEC.
[1] J. Heidmann and H. A. Bethe, Phys. Rev. **84**, 274 (1951).
[2] Hughes, Garth, and Eggler, Phys. Rev. **84**, 234 (1951).

U6. Slow Neutron Resonances in In^{113} and In^{115}.* V. L. SAILOR, *Brookhaven National Laboratory*.—The total cross section of indium has been measured in the energy range 0.6 ev to 30 ev using the BNL crystal spectrometer.[1] The resonant energies are as follows:

In^{113}	In^{115}
4.69±0.03 ev	1.458±0.003 ev
14.8±0.2	3.86 ±0.02
22–26 (two or more not resolved)	9.16 ±0.05
	12.1 ±0.1
	23.5 ±1.0(?).

The large In^{115} resonance has been carefully measured several times using LiF and Be for the monochromating crystal. The results give $E_0 = 1.458 \pm 0.003$ ev. Isotopic assignments of the resonances listed in the table were made by using enriched isotopes.[2] The assignments of the 3.86- and 9.16-ev resonances were checked by activation of the fifty-four minute half-life of In^{116}.

* Research performed under the auspices of the AEC.
[1] L. B. Borst and V. L. Sailor, Phys. Rev. **85**, 711(A) (1952).
[2] The enriched samples were obtained on loan from the Isotope Research and Production Division of the AEC.

U7. Neutron Resonances in Hafnium Isotopes and in Arsenic. S. P. HARRIS, *Argonne National Laboratory and Illinois Institute of Technology*, AND L. M. BOLLINGER, *Argonne National Laboratory*.—With the high speed mechanical neutron velocity selector,[1] five of the six stable isotopes of hafnium[2,3] as oxides, and also normal hafnium oxide were examined for resonances. Resonances at 1.1, 2.3, 5.7, 6.4, and 7.6 ev were resolved in normal hafnium. The isotopic assignment of these resonances is as follows:

Energy of resonance	Isotope
1.1 ev	Hf^{177}
2.3	Hf^{177}
5.7	Hf^{179} and probably also Hf^{177}
6.4	Hf^{177}
7.6	Hf^{178}

In Hf^{177} an additional weaker resonance is seen at 8.7 ev. Measurement of elemental arsenic[4] gave results indicating a prominent resonance at 46±2 ev and a partially resolved group of resonances in the region 500–10,000 ev. There are indications of a possible resonance at ~95 ev. Transmission curves will be shown for the above resonances.

[1] W. Selove, Phys. Rev. **84**, 869 (1951).
[2] Egelstaff and Taylor, Nature **167**, 896 (1951).
[3] Taylor, Anderson, and Havens, Science **114**, 341 (1951).
[4] S. P. Harris and A. S. Langsdorf, Jr., Phys. Rev. **74**, 1216(A) (1948).

U8. Internal Conversion of Neutron Capture γ-Rays. CARL T. HIBDON AND C. O. MUEHLHAUSE, *Argonne National Laboratory*.—A constant magnetic field 180° film recording electron spectrograph was provided with a collimator for passing a neutron beam through the source position.[1] Internal conversion lines of low energy capture γ-rays for a number of samples were measured and are tabulated in Table I. Note that a cross-over transition in Dy is indicated.

TABLE I.

Compound nucleus	$E\beta$	K	L_{II}	L_{III}	M	$E\gamma$
$_{48}Cd^{114}$	72.8	26.8				99.6
	96.4			3.5		99.9
	551.0	26.8				577.8
$_{62}Sm^{150}$	300.0	46.9				346.9
	340.0			6.7		346.7
	406.5	46.9				453.4
	447.0			6.7		453.7
$_{66}Dy^{165}$	76.7		8.6			85.3
	77.5			7.8		85.3
	~82				~2	~84
	98.8		$9.1 - L_I$(?)			107.9
	139.9	53.8				193.7
$_{80}Hg^{200}$	~279		~14			~293
	~291				~2	~293

[1] C. T. Hibdon and C. O. Muehlhause, Phys. Rev. **83**, 235 (1951).

SATURDAY MORNING AT 9:30
Shoreham, Main Ballroom
(R. G. HERB presiding)

Elementary-Particle Scattering

UA1. Theory of Elementary-Particle Scattering. G. BREIT, *Yale University*. (30 min.)

UA2. Proton Scattering Experiments with the Rochester 130-Inch Cyclotron. C. L. OXLEY, *University of Rochester*. (30 min.)

UA3. Neutron Scattering Experiments with the Rochester 130-Inch Cyclotron. A. ROBERTS, *University of Rochester*. (30 min.)

UA4. The Scattering of Protons by Protons (I).* J. N. McGruer, D. E. Findley,† and H. R. Worthington, *University of Wisconsin.*—The scattering of protons by protons has been observed in the angular range from 6° to 45° (laboratory angles) and at several energies between 1.8 and 4.2 Mev. Monoenergetic protons were incident upon a gas target and scattered protons were detected in a proportional counter. The primary purpose of this experiment was to improve the accuracy over that of previous work. In order to facilitate the accurate determination of geometrical quantities the scale of the equipment was large, the scattering chamber proper being 36-in. i.d. Elimination of the usual entrance foil by a differential pumping arrangement permitted collimation of the incident beam to a half-angle of 6 min, and the use of a large aperture collector cup insured the collection of all but a negligible fraction of the incident beam. At least 200,000 counts were taken at each point, and the scattering gas was continuously monitored for the presence of contaminants. With these precautions it was possible to assign a probable error of approximately ±0.3 percent to the values obtained for the cross sections between 15° and 45°.

* This work was supported in part by the Wisconsin Alumni Research Foundation and in part by the AEC.
† Now at North American Aviation, Inc., Downey, California.

UA5. The Scattering of Protons by Protons (II).* H. R. Worthington, D. E. Findley,† and J. N. McGruer, *University of Wisconsin.*—Proton-proton scattering measurements have been made with particular attention to the reduction of errors at small angles. The chamber for this purpose provided an incident beam of 6-min half-angle and an analyzing slit system of 18-min half-angle. The slit dimensions were chosen in such a way that second-order errors in geometry were canceled independently of angle and energy. Three sets of slits of different sizes were used to provide information about slit-edge penetration. All spurious effects involving protons of improper energy were studied quantitatively in the counter. Gas contamination was monitored continuously, and multiple scattering effects were carefully investigated. By these means it was possible to extend the angular range to 6° in the laboratory system. Measurements were made at several energies between 1.8 Mev and 4.2 Mev. At all energies deviations from a pure S wave interaction were observed. The deviations in general were more than twice the magnitude of the experimental uncertainty.

* Work supported in part by the Wisconsin Alumni Research Foundation and in part by the AEC.
† Now at North American Aviation, Inc., Downey, California.

UA6. Scattering of Protons by Protons (III). J. L. Powell and H. H. Hall, *University of Wisconsin.*—The data of WMF[1] were subjected to conventional phase shift analysis. Early work during the course of the experiments established the presence of departures from S wave scattering. Detailed study showed that agreement with experiment could be attained by inclusion of a P wave contribution. No further improvement could be obtained by introduction of angular momenta higher than 1. Final values of S and P phase shifts were obtained by weighted least squares adjustment of K_0 and K_1, weights being assigned according to the experimental uncertainty at each point in the angular range from 6° to 45°. The resultant theoretical cross section was found to fit the experimental data within a few tenths of 1 percent in every case. Experimental uncertainties were such that K_0 was determined to within about ±0.05°. Small negative P phase shifts, amounting to −0.1° at 3.9 Mev, were obtained. The uncertainties in K_1 were just sufficient to allow the expected E energy dependence. Uncertainties in the least squares parameters were determined by normal propagation of the errors given by the experimenters.

[1] See previous abstract.

UA7. Scattering of Protons by Protons (IV). H. H. Hall and J. L. Powell, *University of Wisconsin.*—The new information provided by the above work has been interpreted in terms of static $p-p$ interactions. The S wave results, analyzed from the point of view of the theory of effective range, agree with the older data.[1] An attempt has been made to account for the observed magnitude and sign of the P contribution in terms of conventional triplet interactions including Majorana exchange. The assumption of charge independence in triplet states allows the determination of potential parameters[2] except for exchange. The amount of exchange within the limits set by the present data is quite insensitive to choice of parameters, provided they are consistent with the properties of the deuteron. Several selections of parameters, based on the work of Feshbach and Schwinger,[2] lead to the conclusion that the effect of exchange is approximately expressed by $(0.35+0.65P_x)$. Preliminary estimates indicate that the numbers given above are determined by the present $p-p$ data to within about ±20 percent. Work is in progress to estimate the consequences of these conclusions at higher energy.

[1] Jackson and Blatt, Revs. Modern Phys. **22**, 77 (1950); Breit and Hatcher, Phys. Rev. **78**, 110 (1950).
[2] Feshbach and Schwinger, Phys. Rev. **84**, 194 (1951).

UA8. $p-p$ Scattering at 18.3 Mev.* J. L. Yntema and M. G. White, *Princeton University.*—The differential cross section for the scattering of protons by protons at 18.3±0.2 Mev has been measured over the range 90° to 30° in the center-of-mass system. Polystyrene and polyethylene foils were used as scatterers, and the cross section was determined by counting coincidences between the scattered and recoil protons. The protons were detected by anthracene scintillation counters. The coincidence circuit was of the shorted line type with a resolving time of 0.05 μsec. The absolute probable error is estimated to be 1 percent at 90°. The relative probable errors of the 80° to 30° points with respect to the 90° point vary from 0.7 percent to about 2 percent. The nuclear scattering does not appear to be spherically symmetric. The data will be compared with the potential proposed by Christian and Noyes.[1]

* Assisted in part by the AEC and the Higgins Trust Fund.
[1] R. S. Christian and H. P. Noyes, Phys. Rev. **79**, 85 (1950).

UA9. The Angular Distribution of Neutron-Proton Scattering at 14 Mev. William G. Cross, *Chalk River Laboratory.*—The differential pulse-height distribution from a stilbene scintillation counter exposed to 14-Mev $T-D$ neutrons is used to derive the energy distribution of recoil protons produced in the crystal and hence their angular distribution. The relation for stilbene between pulse height and proton energy was measured with monoenergetic protons from the $He^3(d, p)He^4$ reaction, the proton energy being varied by aluminum absorbers. Theoretical expressions were derived for the distortion of the proton spectrum by protons escaping from the crystal and by double scattering of the neutrons in it, and were verified by observing the changes in pulse-height distribution for crystals of various shapes and sizes. A crystal size was chosen which minimized the uncertainties resulting from these effects. Only the upper half of the proton energy spectrum was used (corresponding to neutrons scattered between 90° and 180° in c. m. system) and was spread over thirty channels of a differential pulse-height analyzer. Over this range the angular distribution was found to be uniform. Statistical errors were 1.5 percent per channel. The uncertainty in deiriving the angular distribution is at present ±5 percent but may be reduced to 3 percent by better measurement of the energy-pulse-height relation.

Saturday Morning at 9:30

Wardman Park, Burgundy Room

(F. J. Dyson presiding)

Theoretical Physics, Including Field Theory

V1. Matter-Matter Interaction Through Retarded Fields. Frederik J. Belinfante, *Purdue University.*—Expressing matter-matter interaction-through-fields in merely matter variables can in static approximation be done by substituting in half the field-matter interaction term of the Hamiltonian, the static approximation of the field generated by the matter. The "missing" half of the interaction energy is canceled by the static approximation of the field energy. Also in the relativistic case, half the interaction energy is canceled but partially by perturbation of the matter energy ("recoil"). Yet don't simply substitute the retarded approximation. First, the fields in interaction representation should be split into creation and annihilation terms. Then, place all creation terms left and annihilation terms right of the matter factor in the interaction and express them by Fourier expansion in terms of the spatial field distribution. (*E.g.*, in quantum electrodynamics, $\mathfrak{E}^{(+)}(\mathbf{x}, t)$ as function of $\mathfrak{E}(\mathbf{x}', t)$ and $\mathfrak{A}(\mathbf{x}', t)$.) Only in the resulting expression substitute in Heisenberg representation the retarded solution. This yields the second-order interaction energy obtainable also by perturbation theory taking into account recoil of matter in virtual intermediate states. The validity of this method is proved using auxiliary conditions.[1]

[1] F. J. Belinfante, Phys. Rev. **84**, 644 (1951).

V2. The Nonlinear Interaction of Scalar Fields. M. Dresden, *University of Kansas.*—In most problems in field theory the coupling term between the different fields is nonlinear. To investigate the specific nonlinear features a simple model was examined. The system considered, consisted of two scalar real fields with a coupling term in the Lagrangian of the form $g\psi_1{}^2\psi_2$. The cubic term was motivated by the occurrence of that type of coupling in the Dirac-Maxwell case. In the course of the investigation it appeared useful to introduce an auxiliary system with which the coupled system could be compared. The auxiliary system consisted of a single scalar field, it was described by the ordinary relativistic Lagrangian with a term $g\psi^3$ added. The phase space methods used by Finkelstein, LeLevier, and Ruderman[1] were applicable, with minor modifications, to the auxiliary problem. One obtains the result that singularity free, square integrable solutions of the classical field equation exist, provided a condition involving g is satisfied. The discussion of the coupled system follows the same general pattern as that of the auxiliary system. Since the phase space is four dimensional in this case, the geometrical discussion becomes more involved; the general conclusions, however, remain much the same.

[1] Finkelstein, LeLevier, and Ruderman, Phys. Rev. **83**, 329 (1951).

V3. On the Quantization of Interacting Gravitational, Electromagnetic and Electron Fields.* R. Skinner and A. Schild, *Carnegie Institute of Technology.*—This paper is an extension of previous work[1,2] on the quantization of the gravitational field of general relativity. The gravitational field is described by a quadruped of 4 vectors $h_\mu{}^{(\alpha)}$ in terms of which the metric tensor can be defined by $g_{\mu\nu} \equiv \eta_{(\alpha\beta)} h_\mu{}^{(\alpha)} h_\nu{}^{(\beta)}$, where $\eta_{(\alpha\beta)}$ are the constant components of a Minkowski metric. The electromagnetic field variables are the potentials A_μ, and the electron field variables the Dirac spinors ψ and $\bar{\psi} \equiv \psi^\dagger \gamma^{(4)}$; the Dirac matrices $\gamma^{(\alpha)}$ are treated as constants. The momentum field variables are defined with respect to the family of 3-surfaces $x^4 = \text{constant}$. The Hamiltonian of the three fields is obtained. It contains velocity terms which remain arbitrary and correspond to the 5-fold freedom in the choice of coordinates x^μ and of the electromagnetic gauge and to the 6-fold freedom in the choice of the quadruped $h_\mu{}^{(\alpha)}$ which can undergo arbitrary rigid rotations at each point of space time. The Hamiltonian is being examined to see whether it can be put into a form suitable for Fermi-Dirac quantization of the electron field.

* Partially supported by the Flight Research Laboratory, U. S. Air Force.
[1] F. A. E. Pirani and A. Schild, Phys. Rev. **79**, 986 (1950).
[2] F. A. E. Pirani, D.Sc. thesis, Carnegie Institute of Technology (May, 1951).

V4. Radiation Force and Torque. Harold Levine and Julian Schwinger, *Harvard University.*—The force and torque on an object situated in a progressive wave field are related to the asymptotic scattering amplitude and therefore share its well-known stationary property. As an illustration consider plane sound waves impinging on a rigid disk. Let $A(\vartheta, \alpha)$ be the amplitude for scattering from an incident direction α to the direction ϑ, both angles measured from the disk normal. Then the time average normal force on the disk is $F = 2\pi\rho_0 k \cos\alpha \operatorname{Im} A(\alpha, \alpha) = \frac{1}{2}\rho_0 k^2 \cos\alpha\sigma(\alpha)$, and the time average torque about an axis perpendicular to the plane of incidence is $T = 2\pi\rho_0 \operatorname{Re}[\partial/\partial\vartheta A(\vartheta, \alpha)]_{\vartheta=\alpha}$. In these equations ρ_0 denotes the equilibrium density of the medium, k the magnitude of the wave vector, and $\sigma(\alpha)$ the total scattering cross section for wave incident at the angle α. Application of the torque relation to a Rayleigh disk will be discussed.

V5. Quantum Corrections to Classical Nonlinear Meson Theory. D. R. Yennie,* *Institute for Advanced Study.*—Recently interest has arisen in the possibility of using nonlinear meson fields to account for certain nuclear properties.[1] Such calculations treat the meson field classically by assuming that quantum fluctuations are negligible for large classical field strengths. To investigate this assumption, we consider a quantized theory with a nonlinear term $\lambda\varphi^4$ in the Hamiltonian. Using Schiff's canonical transformation,[2] the Hamiltonian becomes the sum of the classical energy and a quantum part with coefficients depending on the classical field. For the part of the Hamiltonian quadratic in the quantum field the definitions of the vacuum and the vacuum energy depend on the classical field which provides a potential for the quantized field. After subtracting certain renormalizations from this vacuum energy, a finite correction to the classical energy is obtained. With increasing field strength, the correction arising from this quasi-potential becomes increasingly important relative to the classicaly terms usually considered, contrary to general belief. Unfortunately, higher order corrections are harder to esimate and the present calculation serves only as an indication of the point at which quantum corrections become important.

* National Research Fellow.
[1] L. I. Schiff, Phys. Rev. **84**, 1 (1951).
[2] L. I. Schiff, Bull. Am. Phys. Soc. **27**, No. 1, Abstract Y2.

V6. Gauge Invariance and Classical Electrodynamics. Lloyd Motz, *Columbia University.*—If one starts from the gauge invariant tensor $G_{\mu\nu} = \lambda g_{\mu\nu} + F_{\mu\nu}$, where λ is an invariant function of a four-vector A_μ, $g_{\mu\nu}$ is the metric tensor, and $F_{\mu\nu}$ is equal to curlA_μ, then $(-|G_{\mu\nu}|)^{\frac{1}{2}}d\tau$ is the simplest gauge invariant volume element that can be obtained. $|G_{\mu\nu}|$ is the determinant associated with $G_{\mu\nu}$. In a Galilean system this determinant becomes $-\{(E\times B)^2+[\lambda^2+\frac{1}{2}(B^2-E^2)]^2-\frac{1}{4}(B^2+E^2)^2\}$, where E and B are identified with $F_{\mu\nu}$ in the usual way. If we take for the Lagrangian density of the electromagnetic field the square root of the negative of this expression, we obtain the rational expression $\{-\gamma\cdot(E\times B)-\gamma_4[\lambda^2+\frac{1}{2}(B^2-E^2)]-\frac{1}{2}i\gamma_5(B^2+E^2)\}$, where $\gamma=(\gamma_1,\gamma_2,\gamma_3)$, γ_4 and $\gamma_5=\gamma_1\gamma_2\gamma_3\gamma_4$ are the Dirac matrices. The space components of E and B are taken as four component column matrices. The usual variational principle leads to a set of linear Maxwell-Lorentz field equations for both positive and negative charge distributions which are defined in terms of the four-vector A_μ. The velocity of the charge distribution is identical with that obtained from the usual retarded potentials for a point charge. For the static case the electrostatic potential is given as the solution of the equation $\nabla^2\phi=2\lambda\Phi$. For an appropriate choice of λ it is always possible to find a solution that is finite everywhere.

V7. A Possible Convergent Solution of the Interaction Sttea Equation. JACK HELLER, *Cambridge University*.—A solution Ψ, of the state equation which reflects the believed nonanalytic behavior[1-3] of Ψ at the value of the coupling constant $\alpha=0$, is obtained by assuming a solution of the form $\Psi=BL+R$ where B has a branch point and L and R essential singularities at $\alpha=0$. L and R can be expanded about the origin in the coupling constant plane, if the essential singularity is isolated. Since B cannot be expanded about the origin, the assumed solution is then expanded in a Taylor series about a point $\alpha_0\neq 0$. The expanded solution is substituted into the state equation and recurrence relations are found by the usual equating of powers. Although the recurrence relations are very complex, two things can be inferred. (1) There must be an essential singularity at $\alpha=\infty$, and (2) the initial condition of noninteracting fields cannot be used, if the assumed solution exists.

[1] C. A. Hurst, Trinity College (Cambridge) Fellowship thesis (1951).
[2] W. Sollfrey and G. Goertzel, Phys. Rev. **83**, 1038 (1951).
[3] V. F. Weisskopf, Det. Kgl. Danske. Videnskab. Selskab. Mat.-fys. Medd. **14**, 6 (1936).

V8. A Rational Relativistic Single Particle Theory. T. A. WELTON, *Oak Ridge National Laboratory*.—A simple description of a single electron interaction with the radiation field has been developed, using as the starting point an obvious parameterization of the Dirac equation. At this level no pair production is possible, and only single electron processes can be calculated. No supplementary condition is used or required, and obvious covariance is maintained at every step. The result for the free electron mass correction is identical in form with that given by Feynman. A parallel treatment for the scalar charged particle yields also a logarithmically divergent result. The radiative corrections to the scattering matrix are identical with those obtained by Feynman, except that the closed loop contributions do not appear. It in fact appears likely that the real virtue of this formalism lies in its derivation from a new point of view of the prescriptions given by Feynman. By use of this formalism it can easily be shown that the formal divergence of the mass correction is an artifact of the perturbation theory. It can further be rendered plausible that the mass correction is actually approximately equal to the unperturbed mass, without the introduction of any length in the theory aside from the Compton wavelength.

V9. The Octupole Moment Interaction. W. A. NIERENBERG, *University of California, Berkeley*.*—The matrix elements of the octupole interaction, diagonal in I and J, of two systems of angular momentum **I** and **J** can be found in several papers in the literature.[1] The various expressions are usually given as the eigenvalues of the operator (in an $\mathbf{I}+\mathbf{J}=\mathbf{F}$, F_z representation). Unfortunately, no two of the expressions agree. It seemed reasonable, therefore, to recalculate the matrix elements by an entirely different method. The correct eigenvalues are given by

$$O=C^3-4C^2+\tfrac{4}{3}C\{-3I(I+1)J(J+1)+I(I+1)+J(J+1)+3\}+4I(I+1)J(J+1)$$
$$C=I(I+1)+J(J+1)-F(F+1).$$

This expression agrees with that given by Kramers.[1] The method used to obtain this result is applicable to higher harmonics and is well suited to supplement Kramers' results by the ease of numerical computation in the application to higher moments. In essence the method involves the spherical addition theorem applied to $P_l(\cos\Theta_{IJ})$ and recognition of the fact that only the $P_l^0(\cos\theta_I)P_l^0(\cos\theta_J)$ contribute to the diagonal matrix elements. The eigenvalues are then obtained by a suitable symmetrization of $P_l^0(\cos\theta_I)P_l^0(\cos\theta_J)$ and a "subtraction along the diagonal" process.

* This research has been assisted in part by the ONR.
[1] H. A. Kramers, Proc. Roy. Acad. Amsterdam **34**, 965 (1931). H. B. G. Casimir and G. Kaneman, Physica **9**, 494 (1942). Davis, Jr., Nagle, and Zacharias, Phys. Rev. **76**, 1068 (1949).

V10. Multiple Compton Scattering of Low Energy Gamma-Radiation. R. C. O'ROURKE, *Naval Research Laboratory*.—The transport equation for multiple Compton scattering of low energy ($E\ll\frac{1}{2}$ Mev) gamma-radiation in infinite plane parallel media is set up by means of Marshak's[1] method of spherical harmonics. The basic problem to be solved is the broadening of an incident monochromatic spectral distribution by multiple Compton scattering. The present approach eliminates many of the approximations used by the author in a previous paper.[2] Explicit expressions in the form of Fourier integrals have been obtained in the P_1 and P_2 approximations for a semi-infinite medium. A numerical investigation of these Fourier integrals and others for the finite medium is in progress. Results for the semi-infinite medium will be presented.

[1] R. C. Marshak, Phys. Rev. **71**, 443 (1947).
[2] R. C. O'Rourke, Phys. Rev. (to be published).

V11. Configuration Interaction in Iron Group Elements.* N. ROSENZWEIG, *Argonne National Laboratory*.—The spectroscopic terms assigned to the odd configurations $3d^{n-2}4s4p$ and $3d^{n-1}4p$ overlap considerably. Therefore, a theoretical treatment must frequently include a consideration of the matrix components of the electrostatic interaction between the two configurations. Accordingly, using Racah's methods,[1] the matrix components

$$\left[3d^{n-2}\alpha_1S_1L_14s(S_2L_2)4pSL\left|\sum_{i<j}\frac{e^2}{r_{ij}}\right|3d^{n-1}\alpha_3S_3L_34pSL\right] \quad (1)$$

have been expressed as linear combinations of the appropriate Slater integrals $R^2(3d3d,\,3d4s)$, $R^2(4s4p,\,4p3d)$, and $R^1(4s4p,\,3d4p)$. A relatively small set of tables containing coefficients suffices for the construction of (1) for all the combinations of the quantum numbers in the scheme. These tables will be published soon.

* Work done partly as Ph.D. thesis, Cornell 1951.
[1] G. Racah, Phys. Rev. **62**, 438 (1942); **63**, 367 (1943).

V12. Outer Electron Structure and the Z Dependence of the X-ray *K* Level Values for Heavy Atoms.* J. E. MACK, *University of Wisconsin*.—Ingelstam[1] has noticed and investigated inconclusively the broken-curve character of the K level Mosely diagram for the heavy elements ($Z\gtrsim 50$). In a modified Mosely diagram in which the ordinate is a linear function of $(\nu_{\mathrm{Dirac}}/R)^{\frac{1}{2}}-(\nu_{\mathrm{obs}}/R)^{\frac{1}{2}}$, where ν_{Dirac} is the ionizing energy of a hydrogen-like atom calculated according to the Dirac theory, the curve may be approximated by a broken line in which the breaks are correlated with the beginnings of new outer shells, as in the well-known outer screening number plots of

Sommerfeld for the L and M levels. If it were possible to calculate the K levels for screened electrons sufficiently accurately, the K levels of heavy atoms would make appropriate material for detecting deviations (e.g., Lamb shift, finite nuclear size) from the simple Dirac relativistic model of the electron in an atom.

* A detailed report will be submitted to *Arkiv för Fysik* for publication.
[1] E. Ingelstam, Nova Acta Regial Soc. Sci. Upsaliensis IV, **10**, No. 5 (1937); especially, Fig. 25 and pp. 97–99.

V13. On a Relation between Phase-Shifts and Energy Levels. P. WEISS, *General Electric Company*.—In the theory of scattering by an attractive central field, the number of bound states in general equals the number of half-cycles through which the phase-shift varies as the energy varies from infinity to zero.[1] For simplicity take the case of S scattering. Then this relationship is easily proved by the use of the Jost function[2,3] $f(k)$ which is the limit for $r\to 0$ of that solution of the equation $(d^2u/dr^2)+(k^2-V(r))u=0$, $r\geq 0$, $V(r)<0$, which for large values of r behaves asymptotically like e^{-ikr}. Jost has shown that the amplitude of $f(k)$ is the phase-shift. A standard theorem of analytic function theory[4] states that the amplitude variation round a closed curve C of a function analytic inside C is 2π times the number of zeros of the function inside C. Apply this theorem to $f(k)$ as a function of the complex energy parameter k, the curve C being the infinite semicircle of the lower k half-plane. One can show that all the zeros of $f(k)$ lie on the imaginary axis and the result follows.

[1] Mott and Massey, *Atomic Collisions*, second edition, 31 (1949).
[2] R. Jost, Helv. Phys. Acta **20**, 256 (1947).
[3] V. Bargmann, Revs. Modern Phys. **21**, 488 (1949).
[4] E. C. Titchmarsh, *The Theory of Functions* (1939), second edition, p. 116.

SATURDAY MORNING AT 9:30

Shoreham, Terrace Room

(E. BRIGHT WILSON presiding)

Nuclear Magnetic Resonance; Microwave Spectra

VA1. Nuclear Resonance Spectrum of a System of Four Nuclei. R. BERSOHN, *Cornell University*.—The nuclear resonance absorption spectrum of several powdered ammonium salts has been measured, and the dimensions of the tetrahedral ammonium ion were determined from the second moments of the absorption curves.[1] Idealizing the solid as a collection of independent systems of four equidistant dipoles enables the line shape to be calculated. Unfortunately, a cubic and a quartic secular equation must be solved unless the external magnetic field coincides with a two or a threefold symmetry axis of the tetrahedron or a tetrahedral edge in which case only quadratics need be solved. The principal results are (1) a qualitative agreement with the observed line shape, and (2) a prediction of the line shape anisotropy to be expected in a single crystal. In particular the nuclear resonance absorption study of a single crystal of an ammonium halide can determine the randomness of orientation of the ammonium ions, barring the existence of domains.

[1] H. S. Gutowsky and G. E. Pake, J. Chem. Phys. **16**, 1164 (1948); **17** 972 (1949).

VA2. Broadening of Magnetic Resonance Lines in Metals by Spin-Lattice Interactions.* H. S. GUTOWSKY AND B. R. MCGARVEY, *University of Illinois*.—Nuclear magnetic resonance line shapes and widths, their temperature dependence, and the conduction electron shifts[1] in resonance frequency are reported for the metals lithium, sodium, rubidium, cesium, aluminum, copper, and gallium. The absorption lines in most of these metals are broader than predicted for nuclear magnetic dipolar broadening alone.[2] We propose that the mechanism responsible for most, if not all, of this additional broadening is the interaction between the nuclear spins and the conduction electrons, which also determines the spin-lattice relaxation time. Spin-lattice relaxation times T_1 are estimated from the nondipolar broadening of the experimental absorption lines. These T_1 values compare favorably with available directly measured values and with approximate T_1 values obtained by Korringa's theory[3] from the measured resonance shifts. In the case of lithium a dipolar line-wdith transition was observed at 255°K; this transition results from self-diffusion, for which we determine an activation energy of 9.8±1 kcal/mole.

* Supported in part by the ONR.
[1] W. D. Knight, Phys. Rev. **76**, 1259 (1949).
[2] H. S. Gutowsky, Phys. Rev. **83**, 1073 (1951).
[3] J. Korringa, Physica **16**, 601 (1950).

VA3. The Microwave Spectrum of $C_8H_{13}Br$.* A. H. NETHERCOT, A. JAVAN, AND C. H. TOWNES, *Columbia University*.—The spectrum of the molecule 1-bromo, bicyclo [2, 2, 2] octane[1] is that of a symmetric top. Absorption bands have been studied for the transitions originating from the levels $J=5$, 15, 16, and 17. The half-width of these unresolved bands is approximately 20 Mc. The B values are 718.85±0.07 and 726.20±0.07 Mc for the two isotopes. The observed frequencies, which indicate no appreciable centrifugal distortion, are

Br^{81}	8627.5	22,997	24,441	25,882
Br^{79}	8716.5	23,231	24,691	26,146.

Assuming the C−Br distance to be 1.939A, the C−H distance 1.10A, and all angles tetrahedral, the calculated B values indicate either that the C−C distance is 1.555±0.003A and the molecule is not twisted or that it is 1.573A, the infrared value for ethane,[2] and the average angle at which the upper four carbon atoms are twisted is ~11.3°. This distance is in either case greater than 1.542.

* Work supported jointly by the Signal Corps and ONR.
[1] This molecule was synthesized and kindly made available for this investigation by Professor W. Doering and A. Sayigh, Department of Chemistry, Columbia University.
[2] L. G. Smith and W. M. Woodward, Phys. Rev. **61**, 386 (1942).

VA4. The Microwave Spectrum of Nitryl Fluoride. D. F. SMITH AND D. W. MAGNUSON, *Carbide and Carbon Chemicals Company*.—Eight lines in the microwave spectrum of NO_2F have been identified. The absence of transitions between levels of nuclear species "a" show that NO_2F is a planar molecule with a C_{2v} axis. The moments of inertia (in atomic mass units Angstroms[2]) $I_a=38.28_6$, $I_b=44.15_9$, and $I_c=82.59_0$, are in accord with this since $I_c-I_a-I_b=0.14_5$. If the ONO angle is assumed to be 125°, the NF distance is 1.35A and the NO distance is 1.23A. The dipole moment is 0.47 Debye unit. The hyperfine structure has been incompletely resolved for only two transitions. These splittings give only approximate values of the quadrupole coupling coefficients. These are $\chi_{aa}=0.7$ mc/sec, $\chi_{bb}=1.5$ mc/sec, and $\chi_{cc}=-2.2$ mc/sec.

VA5. Microwave Spectrum of Methylene Fluoride.* D. R. LIDE, JR.,† *Harvard University.*—Approximately thirty-five lines in the microwave rotational spectrum of the slightly asymmetric rotor CH_2F_2 have been observed in the 17,000 to 32,000 mc region. The most prominent feature of the spectrum is a series of close doublets which result from the asymmetry splitting of levels of high J and K which are degenerate in the limiting prolate symmetric rotor. The application of the Wang splitting formula to this series, together with Stark effect measurements on several low J lines, has led to a complete analysis of the spectrum. The rotational constants a, b, c are 49,138 mc, 10,604 mc, and 9249 mc, respectively. With the aid of one line of $C^{13}H_2F_2$, found in natural abundance, the four structural parameters of the molecule have been determined. Preliminary values are $r_{CF}=1.36A$, $r_{CH}=1.09A$, $\angle FCF=108°$, $\angle HCH=112°$. The dipole moment was calculated from the Stark effect of the $2_{12}\rightarrow 3_{03}$ transition to be 1.93 Debye units. The structural parameters of CH_2F_2 will be discussed in relation to similar molecules.

* Supported in part by the ONR.
† Standard Oil of California Predoctoral Fellow.

VA6. Microwave Spectrum of MnO_3F.* A. JAVAN, *Columbia University*, AND A. V. GROSSE, *Temple University.*—The symmetric top molecule MnO_3F has been prepared and the $J=2\rightarrow 3$ transition observed in the microwave region. The The quadrupole hfs confirms a spin of 5/2 for Mn^{55} and gives a quadrupole coupling constant of $+16.8$ mc. The B value for the molecule is 4129.11 mc. Because O^{16} has zero spin and the molecule has C_{3v} symmetry only levels with k a multiple of 3 can occur in the ground state. In excited degenerate vibrational states, however, levels satisfying the condition $k-l$ equals a multiple of 3 can occur and are observed. Three excited vibrational states with the following values of α have been detected: -12.8, 5.8 and 7.77 mc. The first two are due to degenerate excited states and undergo an l-type doubling splitting. The values of the l-type doubling constants are 14.6 and 8.64 mc. The authors wish to thank Professor C. H. Townes for many helpful discussions on this problem.

* Work supported by AEC.

VA7. Pressure Broadening of O_2^{16} Lines in the Millimeter Wavelength Region.* J. O. ARTMAN AND J. P. GORDON, *Columbia University.*—A large nonresonant cavity has been used to investigate self-broadening of O_2 lines in the 5 mm wavelength region. O_2-N_2 cross sections were determined by the decrease in line intensity upon addition of N_2. Individual O_2 lines were observed at pressures of several mm Hg; absorption of O_2 in air at atmospheric pressure was also measured. The average value of the line-breadth parameter $\Delta\nu/P$ for lines of rotational quantum number $K=3$ to $K=13$ is 1.9 mc/mm Hg. A slight decrease of line breadth with increasing K is apparent. From individual O_2 line measurements the N_2-O_2 broadening effect is reasonably constant at 0.9 of the self-broadening parameter. The observed O_2 half-widths can be expressed as the sum of a K-independent short range force contribution of 1.31 mc/mm Hg and a polarizibility interaction[1] calculable from known molecular constants. The short-range force contribution corresponds to the viscosity-heat conduction collision frequency. O_2 molecular quadrupole interaction broadening appears to be negligible. No evidence has been found for the peak in $\Delta\nu/P$ at $K=7$ observed by Anderson.[2]

* Work supported jointly by the Signal Corps and ONR.
[1] P. W. Anderson, thesis, Harvard University, Cambridge, (1948).
[2] Anderson, Smith, and Gordy, Phys. Rev. **82**, 264 (1951).

VA8. Variation of Collision Diameters with Mix Ratio in Binary Mixtures in Microwave Pressure Broadening. L. C. JONES, A. V. BUSHKOVITCH, C. A. POTTER, AND A. G. ROUSE, *Saint Louis University.*—It has been previously found[1] that collision diameters of foreign perturbers determined from pressure broadening of ammonia microwave absorption lines vary with mix ratio. Extensive measurement of the collision diameters of oxygen and helium in binary mixtures with ammonia have now been made using gas mixtures that were chemically analyzed at various pressures to correct the mix ratio. The variation with mix ratio was again observed. A least-squares reduction of the data gave the following results for the variation of collision diameters measured in angstroms: oxygen: $b_{12}=4.79-8.53\times 10^{-3}$ (percent O_2), and helium: $b_{12}=2.46-3.18\times 10^{-3}$ (percent He).

[1] Potter, Bushkovitch, and Rouse, Phys. Rev. **83**, 987 (1951).

VA9. Pure Quadrupole Spectra of Solid Chloroacetic Acids and Substituted Chloroacetic Acids.* H. C. ALLEN, JR., *Harvard University.*—Using a frequency modulated super-regenerative spectrometer similar to that used by Dean and Pound,[1] the pure quadrupole spectrum of Cl^{35} has been measured in $CH_2ClCOOH$, $CHCl_2COOH$, CCl_3COOH, $CCl_3CH(OH)_2$, CCl_3CONH_2, and CCl_3COCl. In each of these compounds multiple lines were observed. In all but CCl_3COCl, these lines were closely spaced and presumably arise from crystallographically nonequivalent chlorines.[2] In CCl_3COCl, a group of lines was observed near 40 mc due to the trichloromethyl group, and a single line due to the more ionically bonded acid chlorine near 34 mc. Where feasible the temperature dependence of the observed lines has been measured and the frequencies extrapolated to 0°K to minimize lattice effects. The spectra have tentatively been interpreted in terms of molecular bonding. From the frequencies, the apparent electron withdrawal effect of the groups observed increases in the following order: $-CH(OH)_2$, $-CONH_2$, $-COOH$, $-COCl$.

* Supported by the ONR.
† AEC Postdoctoral Fellow.
[1] C. Dean and R. V. Pound, J. Chem. Phys. **20**, 195 (1952).
H. G. Dehmelt, Naturwiss. **17**, 398 (1950).

VA10. Anomalous Wavetypes in Waveguides Containing Ferromagnetics.* A. A. TH. M. VAN TRIER, *Columbia University and Physisch Laboratorium R. V. O.—T. N. O., Waalsdorp, Holland.*—Ferromagnetic resonance experiments are often done by means of a wave guide technique which is standard for measurements on isotropic materials. A slab of the material under investigation is placed across the guide and backed in turn by a shorting plate and a quarter-wavelength guide. From the two measured input impedances of the slab one is able to derive the values of the complex $\tilde{\epsilon}$ and $\tilde{\mu}$. However, in ferromagnetic resonance experiments the effects of the induced anisotropy on the wave propagation seem to have been overlooked. The $TE_{0,n}$ wave pattern is different from the pattern which exists in isotropic media. This anomalous wave type and a peculiar boundary value problem which arises from it will be discussed. An infinite series of $TE_{0,n}$ waves must be assumed in both reflection and transmission. The error introduced by neglecting the difference in wave propagation through isotropic and anisotropic media and some numerical data will be given for a typical case.

* Work partly supported by the Signal Corps and ONR.

VA11. Field Expansions in Loss-Free Microwave Junctions. T. TEICHMANN AND E. P. WIGNER, *Princeton University*.—It is found that the short-circuit modes of a loss-free microwave junction, satisfying the boundary conditions $E_{\text{tangential}}=0$ on the surface of the junction and over the (wave guide) openings, are not complete with respect to the fields which may be excited through these openings. It is necessary either to expand in terms of modes satisfying more realistic boundary conditions on the opening (i.e., impedance conditions, relating the tangential components of E and H over the openings) or to add an additional irrotational magnetic field. The first method leads to an admittance matrix (relating the transverse and longitudinal components of the fields in the openings) which is a linear fractional transform of a matrix of the type usually assumed, while the second approach yields a simpler effect in the form of another matrix to be added to the original one. The two final matrices are, of course, equivalent. The additional magnetic field may be expressed in terms of the normal component of H over the openings by means of the Neumann function of the cavity, and it can then be shown that the additive matrix resulting from the irrotational H becomes diagonal if the openings are suitably displaced down the guides. It has nonzero elements only for magnetic guide modes.

VA12. The Nuclear Quadrupole Moment of TA[181]. B. M. BROWN, *Cornell University*.—The nuclear quadrupole moment of Ta^{181} was estimated from the results of hyperfine-structure measurements of the ground state $^5F_1$ of TaII. The most reliable value of the quadrupole coefficient B for the $^5F_1$ state was determined by measurements of the two lines $\lambda 3042.06$ $(36987.73_1 \rightarrow {}^3P_0)$ and $\lambda 2702.80$ $(36987.73_1 \rightarrow {}^5F_1)$. The splitting of the level 36987.73_1 was determined from measurements of the first line, and this splitting and that observed for the second were used to obtain the $^5F_1$ intervals. $B(^5F_1)$ was found to be 0.77×10^{-3} cm^{-1}. The structure and results from two other lines will be discussed. The quadrupole moment was calculated by the Casimir[1] formula with the result $q=5.9\times 10^{-24}$ cm^2. This result is in good agreement with that obtained by Schmidt[2] (6.4×10^{-24} cm^2) from the $^4F_{\frac{3}{2}}$ level of TaI.

[1] H. B. G. Casimir, "On the Interaction between Atomic Nuclei and Electrons," prize essay published by Teylers Tweede Genootschap **11**, (Haarlem, 1936).
[2] T. Schmidt, Z. Physik **121**, 63 (1943).

SATURDAY AFTERNOON AT 2:00

Shoreham, Terrace Room

(S. MILLMAN presiding)

Molecular-Beam Experiments; Paramagnetic Resonance

W1. On the Anomalous Spin Gyromagnetic Ratio of the Electron.* J. G. KING, AND V. JACCARINO, *M.I.T.*—The anomalous spin gyromagnetic ratio of the electron has been obtained from observations of the Zeeman effect of the hyperfine structure interaction in the $P_{\frac{3}{2}}$ and $P_{\frac{1}{2}}$ states of atomic Cl^{35}, using the interaction constants previously determined by the authors.[1] From 8 independent measurements of the atomic g_J values in fields up to 500 gauss a mean value of $g_S=2$ (1.00121 ± 0.00010) was computed. This value of g_S for a closed shell minus an electron agrees with both theoretical[2] and experimental[3] values obtained for a closed shell plus an electron.

* This work has been supported in part by the Signal Corps, the Air Materiel Command, and the ONR.
[1] Jaccarino and King, Phys. Rev. **83**, 471 (1950). King and Jaccarino, Phys. Rev. **84**, 852 (1951).
[2] Schwinger, Phys. Rev. **73**, 416 (1948).
[3] Koenig, Prodell, and Kusch, Phys. Rev. **83**, 687 (1951).

W2. Electron Spin Gyromagnetic Ratio in Atomic Hydrogen.* R. BERINGER AND E. B. RAWSON,† *Yale University*.—The transitions $(M_J=\frac{1}{2}\rightarrow -\frac{1}{2},\ M_I=\frac{1}{2}\rightarrow \frac{1}{2})$ and $(M_J=\frac{1}{2}\rightarrow -\frac{1}{2},\ M_I=-\frac{1}{2}\rightarrow -\frac{1}{2})$ have been observed in a microwave magnetic resonance absorption experiment. Atomic hydrogen is produced in a Wood discharge tube and pumped through a quartz tube which passes through a resonant cavity in a magnetic field. At 8850 Mc/sec the transitions are resonant at about 3400 and 2870 gauss. The signals are observed as in our earlier work with paramagnetic gases. The experiment measures the spin gyromagnetic ratio in the same way as in the precision atomic beam experiment of Koenig, Prodell, and Kusch. The ratio g_J (hydrogen) to g_I (proton) is measured in terms of the microwave cavity frequency, the proton resonance frequency in water at the resonant magnetic field, and the zero field hyperfine separation; and the result of Gardner and Purcell is used to deduce the anomalous spin gyromagnetic ratio. Analysis of our experiment indicates that limitations on precision due to collision and doppler width, field inhomogeneity, field instability, and frequency instability at microwave and proton frequencies will not exceed five parts in a million. Our progress to date in achieving this precision will be discussed.

* Assisted by the ONR.
† AEC Predoctoral Fellow.

W3. Lamb Shift in Ionized Helium.* J. G. HIRSCHBERG, JR., *University of Wisconsin*.—The investigation of the Lamb-shift of the $n=3$ and $n=4$ levels of ionized helium at the University of Wisconsin is reviewed.[1,2] The final method of measurement is described and results presented. The previous method of isolating the interesting faint component with a knife-edge has been abandoned, eliminating the danger of disturbing the intensity distribution. Instead, the primary dispersion has been increased, allowing clear separation of the components so that a knife-edge is unnecessary.

* Supported by the ONR.
[1] J. E. Mack and N. Austern, Phys. Rev. **72**, 972 (1947).
[2] J. G. Hirschberg and J. E. Mack, Phys. Rev. **77**, 745 (1950).

W4. Precision Measurements of the hfs of Rb^{85} and Rb^{87}.* B. BEDERSON AND V. JACCARINO, *M.I.T.*—Using an atomic beam method we have obtained high precision measurements of the Rb^{85} and Rb^{87} hfs interaction energies $(h\Delta\nu)$. The first-order field independent transitions $(F=3,\ m_F=0\leftrightarrow F=2,\ m_F=0)$ and $(F=2,\ m_F=0\leftrightarrow F=1,\ m_F=0)$ for Rb^{85} and Rb^{87}, respectively, were observed in a magnetic field of approximately 0.4 gauss and when corrected to zero field yield the following values: $\Delta\nu(Rb^{85})=3035.735\pm 0.002$ Mc/sec and $\Delta\nu(Rb^{87})=6834.7005\pm 0.0011$ Mc/sec. The above transitions were positively identified by observing the frequencies and widths of all allowed $\Delta F=\pm 1$ transitions. Factors influencing the ultimate accuracy of $\Delta\nu$ determinations (Doppler broadening, resonance widths, stability of rf sources, frequency measurement techniques, etc.) will be discussed and a comparison made of the above data with recent high field measurements.[1] The results of more accurate measurements will be given at this time.

* This work has been supported in part by the Signal Corps, the Air Materiel Command, and ONR.
[1] S. Ochs and P. Kusch, Phys. Rev. **85**, 145 (1952).

W5. Zeeman Effect of Neon in Metastable $^3P_2$ State; Evidence for Zero Spin of $_{10}Ne^{20}$.* G. WEINREICH,† G. TUCKER,‡ AND V. HUGHES, *Columbia University*.—The gyromagnetic ratio of neon ($_{10}Ne^{20}$) in the metastable $^3P_2$ state has been measured by the atomic beam magnetic resonance method at several magnetic fields with the primary objective of obtaining evidence as to whether the spin of $_{10}Ne^{20}$ is zero. The metastable neon atoms were produced in a discharge tube and detected by electron ejection from a wire.[1,2] The results are: $g_J(\mathrm{Ne}, {}^3P_2)=1.501\pm0.001$ at 522 gauss and 1.50 ± 5 percent at 0.5 and 1.2 gauss. These agree with optical measurements by Back[3] at magnetic fields $\sim$30,000 gauss. The linearity of the Zeeman pattern, particularly at low fields, and the absence of line splitting confirm the expected absence of hfs ($<$250 kc/sec). Hence, the nuclear magnetic moment of $_{10}Ne^{20}$ could be no more than $\sim 2.10^{-4}$ nm which is strong evidence that the spin is zero. The ability to produce and detect the metastable states of the rare gases make possible the measurement of their nuclear spins and hfs splittings by the atomic beam magnetic resonance method.

* This research was supported in part by the ONR.
† AEC Predoctoral Fellow.
‡ RCA Predoctoral Fellow, Columbia University, 1950–1951.
[1] V. Hughes and G. Tucker, Phys. Rev. **82**, 322 (1951).
[2] Tucker, Hughes, Rhoderick, and Weinreich, Abstract U7 of February 1952 meeting of American Physical Society.
[3] E. Back, Ann. Physik **76**, 317 (1925).

W6. Radiofrequency Spectroscopy of Deuterium.* R. G. BARNES AND P. J. BRAY, *Harvard University*.—Experiments in magnetic fields of 1900, 3500, and 5100 gauss with the Harvard molecular beam apparatus using the Ramsey separated rf technique permit more accurate evaluation of the rotational-to-nuclear magnetic moment ratio in D_2 in the first rotational state. Using the transitions $m_I=0$, $m_J=0\rightarrow\pm1$ whose frequencies are independent of diamagnetic shielding of the nuclei, the value obtained is $\mu R_D/(1-\sigma_D)\mu_D=0.516550 \pm0.000016$, where σ_D is the diamagnetic shielding correction for μ_D.[1] Comparison with H_2 gives[2] $\mu R_H/\mu R_D=1.993532 \pm0.000096$ whereas the mass-ratio $M_D/M_H=1.998464$. Different zero-point vibrational amplitudes probably account for the discrepancy.[3] These same experiments also measure the dependence of the diamagnetic susceptibility upon the orientation of the molecular angular momentum. The quantity $\xi_\pm-\xi_0$ has the value $-(3.47\pm0.41)$ and $-(3.49\pm0.13) \times10^{-31}$ ergs gauss^{-2} in external fields of 3500 and 5100 gauss, respectively. These agree with the value previously obtained for H_2.[2]

* Supported by the joint program of the ONR and AEC.
[1] N. F. Ramsey, Phys. Rev. **83**, 540 (1951).
[2] Harrick, Barnes, and Bray, Phys. Rev. (to be published).
[3] Private conversation with Professor N. F. Ramsey.

W7. Magnetic Moment Ratios in Hydrogen-Like Molecules.* P. J. BRAY, R. G. BARNES, AND N. J. HARRICK, *Harvard University*.—More accurate measurements of the ratio of the H_2 rotational moment to the D_2 nuclear moment have been made in the molecular beam apparatus. Measurements in the 1800-gauss region yield 1.029014 ± 0.000027 for the ratio of the $H_2 I=0$, $J=2$ resonance frequency to the $D_2 I=2$, $J=0$ resonance frequency measured in the same magnetic field. The difference between this value and the 1.029759 ±0.000017 value for the $H_2 I=1$, $J=1$ case probably arises from internuclear spacing differences caused by different centrifugal forces. Both ratios contain a deuterium nuclear shielding factor $(1-\sigma_D)$ in the denominator. Comparison of molecular beam ratio measurements with the same ratios obtained by nuclear induction and absorption methods is worthwhile, since the former involve no averaging over molecules which undergo collisions. The molecular beam ratio of the $J=0$ H in HD resonance to the $I=2$, $J=0$ D_2 resonance is 3.257207 ± 0.000025. This agrees with the best induction proton-to-deuteron nuclear moment ratio.

* This work supported by the ONR and AEC.
[1] N. F. Ramsey, Phys. Rev. **58**, 226 (1940).
[2] Harrick, Barnes, and Bray, Phys. Rev. (to be published).
[3] N. F. Ramsey, Phys. Rev. **83**, 540 (1951).

W8. Paramagnetic Resonance in Uranium Salts.* S. N. GHOSH, WALTER GORDY, AND D. G. HILL, *Duke University*.—Paramagnetic resonance at microwave frequencies has been observed in the uranium salts UF_3 and UF_4 in powder form. While at room temperature the resonances are very broad and weak, they become significantly stronger and sharper at the temperature of liquid air. The g factors were found to be 2.4 for each salt.

* This research was sponsored by the Air Force Cambridge Research Laboratories.

W9. The Paramagnetic Saturation of Iron Ammonium Alum. W. E. HENRY, *Naval Research Laboratory*.—A previous experiment[1] has shown that for the trivalent chromium ion in potassium chrome alum, the conditions of space quantization of dipoles and the quenching of orbital angular momentum of the $^4F_{3/2}$ state of Cr^{+++} are fulfilled. There appeared to be, however, for Cr^{+++}, a small systematic departure of the magnetic moment (about 3 percent) from the Brillouin function. We have carried out similar experiments with iron ammonium alum in which Fe^{+++} is in a $^6S_{5/2}$ ground state, to see whether or not incomplete quenching is a possible cause of the deviation. We find a similar departure from the Brillouin function for iron ammonium alum, which may be attributable to interaction of the crystalline electric field[2] with the paramagnetic ions. For the highest value of H/T, corresponding to 1.32°K and 52,000 gauss, a 99.64 percent saturation is achieved for iron ammonium alum.

[1] W. E. Henry, Bull. Am. Phys. Soc. **27**, 53 (1952) and Letter to the Editor, Phys. Rev. (to be published).
[2] C. Kittel and J. M. Luttinger, Phys. Rev. **73**, 16 (1948); J. H. van Vleck and W. G. Penney, Phil. Mag. **17**, 961 (1934).

W10. The Crystalline Stark Effect and the Zeeman Effect in Vanadous Tutton Salts. W. W. WADA, *Naval Research Laboratory*.—Under the assumption that a weak electric field of rhombic symmetry is superposed upon a strong field of cubic symmetry, the Stark splitting of the ^4F state and Zeeman splitting of the ground state without free spin assumption have been calculated. It was found that the axial field assumption was not adequate to account for the experimental results, whereas the rhombic field assumption gave the magnetic energy levels that were consistent with the experimental results.[1] Some of the electric field parameters were determined from the experimental results, and the term values of $V(NH_4)_2(SO_4)_2\cdot6H_2O$ under the rhombic field were computed.

[1] Bleaney, Ingram, and Scovil, Proc. Phys. Soc. (London) **64**, 39 (1951).

W11. Paramagnetic Resonance in Phosphors.* W. D. HERSHBERGER AND H. N. LEIFER, *University of California, Los Angeles*.—Paramagnetic studies at 9375 mc have been made on some twenty inorganic phosphors.[1] The sample is contained in a transmission cavity with a Q of 15,000 and the paramagnetic spectrum is obtained by a sweeping technique which yields the derivative of the absorption curve. The specimen in the cavity may be illuminated by ultraviolet light for observations on its spectrum under these conditions. Four phosphors, under condition of no illumination, display line spectra attributed to the manganese ion used as an activator. The simplest spectra, consisting of six lines seven gauss wide and spaced about 65 gauss apart, are obtained with cubic ZnS and cubic $ZnAl_2O_4$. A more complicated 30-line spectrum[2] is found for Mn in hexagonal ZnS, while a line 1000 gauss wide is found for Mn in ZnF_2. When illuminated, the changes in the spectra are such as may be attributed largely to photoconduction.

* Work supported in part by the ONR.
[1] Furnished by H. W. Leverenz of RCA Laboratories.
[2] Schneider and England, Physica 17, 221 (1951).

W12. Paramagnetic Resonance in Concentrated Liquid Solutions. M. A. Garstens and S. H. Liebson, *Naval Research Laboratory.*—The effect of exchange narrowing on line widths has been examined in concentrated water solutions of $Mn(NO_3)_2$. Such solutions are capable of great concentration, and hence, allow a large variation of Mn^{++} ion density, ranging from very low concentrations where the hyperfine structure is easily visible to very high concentrations where the hyperfine lines disappear, and the over-all width of the resonance line goes through a maximum caused by dipolar broadening and then further towards a minimum caused by exchange narrowing. The highly concentrated solutions occur when the salt is allowed to melt in its own waters of hydration. Of great interest is the fact that exchange narrowing not only reduces the broadening due to dipolar interaction among the ions but also appears to reduce that due to interaction between the electrons and the nucleus of the Mn^{++} ion. It thus appears that the hyperfine structure is sensitive to that aspect of the ionic environment which gives rise to exchange interaction.

Saturday Afternoon at 2:00

NBS, Materials and Testing

(W. A. Wildhack presiding)

Instrumentation

WA1. An Isolated Potential-Difference Comparator. T. M. Dauphinee, *National Research Council, Canada.*—A circuit is described for accurate comparison of differences which must remain electrically isolated. A galvanometer or electronic amplifier is used and appreciable potential differences may be maintained between the circuits without affecting the balance. Potentiometric measurements have been made through this "isolated potential comparator" to better than $\pm 0.1\ \mu v$. Error from potential difference between the circuits is less than 2×10^{-6} of the difference for 100-ohm circuits. Within these limits comparisons are accurate to nearly seven figures. A considerable rate of change of the quantities under comparison is permissible. The comparator has been used to measure with high accuracy the emf difference of thermocouples which are electrically connected at the tips. It has also been used to measure the difference between nominally equal standard resistors to several figures or a fraction of a microhm. Only one balance is required; potential or current lead resistance is not significant and no ratio arms are used. In resistance thermometry the circuit permits replacement of the Mueller Bridge by a variable potential lead resistor. All necessity for equality or stability of lead resistance is eliminated.

WA2. A Precision Micromanometer. James M. Kendall, *U. S. Naval Ordnance Laboratory.*—A micromanometer of high accuracy for pressures in the range of 0.1 to 50 mm Hg will be described. This manometer was developed at the Naval Ordnance Laboratory for use with the supersonic wind tunnel. With it a pressure may be read with an error of three microns Hg or less. In order to work out the design of an instrument with this accuracy it was necessary to analyze the optical requirements for accurate reading of the position of a meniscus, and to devise an optical system which meets these requirements. An enlarged image of the meniscus is projected on a screen of the optical system. The entire optical system is raised and lowered by means of a precision lead screw. A fine scale on a drum attached to the lead screw reads directly to 0.05 mm and permits easy estimation to 0.01 mm. The manometer, as will be described, is arranged so that the error caused by the liquid which sticks to the inside surface of the glass tube when the meniscus level is changed, is practically eliminated. Samples of data from which the accuracy of the manometer may be judged will be presented. About six slides will be used to illustrate the presentation.

WA3. A Magnetostriction Magnetometer.* Thomas A. Perls, *National Bureau of Standards.*—Recent work on the change of Young's modulus and internal damping with magnetization[1,2] and on the magnetostrictive vibration of prolate spheroids[3,4] has been investigated for possible application to various instrumentation problems. Magnetostrictively excited vibrations in long rods of various ferromagnetic materials were measured with a small barium-titanate accelerometer attached to one end of the rod. The vibration amplitude was found to vary over several orders of magnitude with changes in the externally applied magnetic field. For a long rod of high permeability, slightly magnetostrictive, permalloy, amplitude changes 10 times greater than the noise level in a narrow-band detector were measured for $\Delta H=4\times 10^{-4}$ oersted. Sensitivity is being greatly improved by the use of an oscillator which is frequency-stabilized by the vibrating rod, and by a determination of the most suitable magnetic material and annealing procedure. The use of fine wires rather than long rods is also being invesitgated.

* Work done under a cooperative program on Basic Instrumentation partially sponsored by the ONR, USAF, and AEC.
[1] F. T. Rogers and S. J. Johnson, J. Appl. Phys. 21, 1067 (1950).
[2] Moyer, Madey, Hildebrand, Knable, and Hales, Phys. Rev. 85, 28(A) (1952).
[3] J. S. Kouvelites and L. W. McKeehan, Rev. Sci. Instr. 22, 108 (1951)
[4] Beck, Kouvelites, and McKeehan, Phys. Rev. 84, 957 (1951).

WA4. Effective Use of Reciprocity in Vibrometer Calibrations. Sanford P. Thompson, *Naval Research Laboratory.*—The basing of vibrometer calibrations upon reciprocity methods can be most effectively achieved through a particular program. As background, the state of the art in vibrometer calibrations by reciprocity will be reviewed. The two procedures[1,2] for effecting calibrations which have been devised on theoretical grounds will be mentioned. One of these procedures has been investigated experimentally;[3-5] comment will be made on the status of this work. For several reasons to be mentioned, it is best to restrict direct reciprocity calibration to instruments especially designed for the purpose. There is indicated a program of designing standard transducers for any particular frequency range, of proving by internal consistency of the calibration data that these standards actually obey the theoretical conditions of the calibration procedure used, and of designing an exciter for the calibration of field instruments by comparison with these standards.

[1] H. M. Trent, J. Appl. Mech. 15, 49 (1948).
[2] S. P. Thompson, J. Acoust. Soc. Am. 21, 538 (1949).
[3] A. London, "The Absolute Calibration of Vibration Pickups," Natl. Bur. Standards Tech. News Bull., January, 1948.
[4] S. P. Thompson, J. Acoust. Soc. Am. 20, 637 (1948).
[5] Mark Harrison, David Taylor Model Basin, Carderock, Md. (to be published).

WA5. The Reciprocity Calibration of Accelerometers. Mark Harrison and Alan O. Sykes, *David Taylor Model Basin.*—Some piezoelectric accelerometers have been calibrated by the reciprocity method from 100 to 10,000 cps. The method has been evaluated theoretically and experimentally. The reciprocity method used is based upon the work of Trent[1] who has formulated the basic equations. Actual calibration systems are often distributed and exhibit wave effects. It has been necessary to extend Trent's equations to include wave effects. In this situation certain dilemmas arise that render difficult the attainment of good accuracy. These dilemmas can be minimized by the design of the accelerometer. These questions are discussed from the point of view of the establishment of a primary standard.

[1] H. M. Trent, J. Appl. Mech. 15, 49 (1948).

WA6. Transient Response of Linear Systems.* J. Frank Koenig, *National Bureau of Standards.*—In the design of an nth order linear system it is desired that the transient response, for given initial conditions, be of a specified form. Criteria are presented for obtaining specified transient responses, for various initial conditions, in linear systems described by nth order characteristic equations. The author's results are presented in the form of theorems which relate the roots and coefficients of the characteristic equation to the transient response, for various initial conditions. One of the theorems gives the conditions on the roots of the nth order characteristic equation such that there will be no overshoot for a step function input to the linear system. Closely related work recently reported by Z. S. Bloch[1] is summarized.

* Work done under a cooperative program on Basic Instrumentation partially sponsored by the ONR, USAF, and AEC.
[1] Z. S. Bloch, Avtomatika i Telemekhanika 11, No. 2 (March–April, 1950).

WA7. An Ultra-Compact Magnetic Storage System. William T. Doyle* and Donald H. Jacobs, *The Jacobs Instrument Company.*—Last year was described[1] a compact and very fast type of magnetic core storage having an access time of two to four microseconds. As originally constructed and used in the JAINCOMP-B electronic digital computer, this type of storage was packaged so that the cores and associated gates for storing three digits were mounted on a single $1\frac{7}{16}\times 2\frac{1}{8}$ in. plug-in subassembly card, the assembly weighing about one ounce. A new version of this type of storage involving a ferritic core material has been developed. This has a storage time of eight microseconds an an access time of three microseconds. Its particular virtue lies in its small size, for 24 digits, with their associated gating circuits. are now all packaged on a single plug-in subassembly of the standard $1\frac{7}{16}\times 2\frac{1}{8}$ in. size, and being $\frac{13}{16}$ in. thick. It occupies the same volume in a computer as a standard plug-in subassembly and weighs $2\frac{3}{4}$ oz.

* Lt. Commander, USN, on temporary assignment from U. S. Naval Postgraduate School, Monterey, California.
[1] D. H. Jacobs and M. May, Phys. Rev. 83, 243(A) (1951).

WA8. A Supersensitive Differential Altimeter. Marcel Martin, Donald H. Jacobs, and Seymour Scholnick, *The Jacobs Instrument Company.*—A need arose for a differential altimeter capable of measuring relatively large altitude changes, over relatively short periods of time, with an accuracy of 0.1 mm of mercury pressure difference. It was found that because of creep, hysteresis, etc., a conventional aneroid capsule would not have the necessary reproducibility of the relationship between pressure and deflection. Hence, it was decided to use a device embodying a diaphragm retained in a fixed (null) position by a servo system, the pressure of the atmosphere being applied to one side of the diaphragm. It was next necessary to find a pressure to apply to the other side of the diaphragm to balance atmospheric pressure. The use of metal springs or similar devices was ruled out because the reproducibility of their stress-strain characteristics could not be relied on because of creep, hysteresis, and so forth. It was finally decided to employ, for the balancing pressure, a "perfect spring" consisting of a trapped volume of gas maintained at constant pressure. The volume of this gas (air) is varied by a piston, and its pressure changes correspondingly in a highly predictable and reproducible fashion. In practice, air at atmospheric pressure is applied to both sides of the diaphragm. When a change in altitude is to be measured, the air on one side of the diaphragm is trapped by a valve and used as the "perfect spring." Changes in altitude are determined by the multiplication of the volume change by the air temperature, and by a constant.

WA9. Addition of a General-Purpose Program to the JAINCOMP-B Electronic Digital Computer. Donald H. Jacobs and Seymour Scholnick, *The Jacobs Instrument Company.*—JAINCOMP-B is a very compact, high speed electronic digital computer which originally[1] contained four wired-in computing programs. This computer, which is asynchronous, has been modified by the addition of an asynchrounous general-purpose programming device. The modified machine is called JAINCOMP-B1. The programming device comprises a punch card reader and associated circuits. The program is set up on a punch card which is divided into 16 vertical columns and 33 horizontal rows. Holes punched in each horizontal row select the computing operations (up to a total of five) that are to be performed in one computing step. Hence each row down the card (except the last) sets up the operations to be performed in a step. A total of 32 computing steps can be set up. This number of steps permits the solution of quite long problems because of the logic used in JAINCOMP-B1. Various special operations such as nonlinear sequencing, iteration, making conditional decisions, etc., are possible. Great programming flexibility is provided by this device. The punch card is supported in a reader which "feels" all hole positions on the card simultaneously. The card is scanned electronically, row by row, by a matrix system. In the last row of the card are punched constants associated with special programming sequences. The punch card system can be modified to accept longer punch cards, affording more program steps, if desired. For programs of still greater length the punch card unit can be supplemented or replaced by a magnetic tape of unlimited length, with a battery of pick-up heads for scanning purposes.

[1] Jacobs, May, and Scholnick, Phys. Rev. 85, 731(A) (1952).

SESSION X

Saturday Afternoon at 2:00

NBS, Chemistry Lecture Room

(J. A. Hornbeck presiding)

Electron-Physics, Including Gas Discharges

X1. Processes Involving Thermal Electrons and Ions in the Mercury Afterglow. Manfred A. Biondi, *Westinghouse Research Laboratories.*—The difficulty in obtaining thermal electrons ($T_e=300°K$) in mercury afterglows[1,2] has been overcome by adding small amounts of helium to the mercury as a "recoil gas." Microwave techniques were used to study the decay of these thermal electrons and ions in the mercury-helium afterglow. The measured ambipolar diffusion coefficient D_a of mercury ions in helium is 790 (cm²/sec) at 1-mm pressure, while mercury ions in mercury give $D_a=10.8$. The first value agrees with theoretical predictions and with measurements on alkali ions in helium; the second value confirms uncertain results quoted by Mierdel.[1] The cross section for electron attachment to mercury is 7×10^{-22} cm², which is the order of magnitude expected for radiative capture of electrons. The electron-ion recombination coefficient for mercury is $\alpha=5\times10^{-7}$ cc/sec, which is one hundred times the value found at higher electron temperatures ($T_e\simeq2000°K$).[2]

[1] Mierdel, Z. Physik **121**, 574 (1943).
[2] P. Dandurand and R. B. Holt, Phys. Rev. **82**, 868 (1951).

X2. Interaction of Electrons and Ions in a Magnetic Field. L. S. Frost* and G. W. Penney, *Carnegie Institute of Technology.*—Experiments have shown that ions and electrons in a magnetic field often behave differently than expected. This paper considers the effect of the usually neglected helical paths followed by electrons in a magnetic field as a result of their thermal energies. It is shown that the Coulomb interactions with ions do not average to zero in a region of complete space charge neutralization, but add up to a net force on each ion and electron. This interaction force is proportional to the relative drift velocity of the ions and electrons, to the electron density, and inversely to the magnetic field strength. The effect of the interaction can be conveniently expressed in terms of an interaction electric field E_i which acts on all charged particles, and must be included in calculations of particle behavior in a magnetic field. The theory applies for magnetic fields making the angular frequency of the helical motion of the electrons greater than the collision frequency.

* Now at Westinghouse Research Laboratories, East Pittsburgh, Pennsylvania.

X3. Multiple Ionization by Electron Impact. William J. Knox, *Yale University.**—In connection with recent interest in the production of multiply charged ions of light elements, some observations have been made on processes in He, N, and O in which two or more electrons are knocked out of an atom by a single incident electron. A mass spectrometer was used to separate ions with different degrees of ionization. The dependence of ion yield on incident electron bombarding current can be used to indicate whether the production process is a single or multiple collision process. Some curves of yield *vs* incident electron energy will be compared to similar curves for rare gases taken by previous experimenters and to calculated curves[1] (for doubly ionized atoms).

* Supported in part by the AEC.
[1] F. de la Ripelle, J. phys. radium **10**, 319 (1949).

X4. Charge Transfer Cross Sections Between Atoms and Slow Ions in A, Ne, and He. Roy F. Potter, *National Bureau of Standards.*—Charge transfer cross sections for slow rare gas ions in their own gases have been studied as a function of the ion energy between 200 ev and 8 ev. The method uses the radiofrequency mass spectrometer to form the primary ion beam. Because no slits are used, relatively little increase in energy spread of the ion beam occurs as the beam enters the reaction chamber. The secondary ion, formed by the transfer of an electron of the neutral atom to the moving ion, has only a small forward velocity component. The primary and secondary beams are separated by applying stopping potentials and getting an energy spectrum having two components, each of which is about 4 ev wide. The three gases He, Ne, and A were used in the studies to compare with previous studies by Hasted[1] and Rostagni.[2] Agreement is found to be within 10 percent throughout most of the region studied. However, in the cases of A and Ne there appears to be a minimum in each curve at approximately 80 ev and 70 ev, respectively. This might be explained by the presence in the primary beam of ions in both the $^2P_{\frac{1}{2}}$ and $^2P_{\frac{3}{2}}$ states.

[1] J. B. Hasted, Proc. Roy. Soc. (London) **205**, 421 (1951).
[2] A. Rostagni, Nuovo cimento **12**, 134 (1935).

X5. Observations on Phenomena Initiated in Gases by an Electric Spark.* H. L. Olsen, R. B. Edmonson, and E. L. Gayhart, *The Johns Hopkins University, Silver Spring.*—Ignition spark phenomena have been photographed in successive stages from zero time to one thousand microseconds. An electronic timer has been used for the introduction of a known time delay between the time of passage of an electric spark (one-half microsecond duration) and a subsequent Schlieren exposure. Individual photographs spaced at time intervals equivalent to a rate of four million frames per second have been obtained. The photographs show the formation, separation, and travel of the shock wave from the spark origin as well as the development of a hot gas kernel remaining behind the shock. The geometrical development of the kernel has been observed for combustible and noncombustible gases. These observations are being used in a study of the ignition process and of the propagation of incipient flames in gases.

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

X6. The Aqueous Electrolyte Cathode in Dielectric Breakdown Studies of Liquids. A. H. Sharbaugh, R. W. Crowe, and J. K. Bragg, *General Electric Research Laboratory.*—The authors' quantitative theory of cathode effects in dielectric breakdown ascribes these effects to field emission from metal cathodes. A cathode which allows systematic investigation of the effects is the aqueous electrolyte cathode employed with dielectric liquids. In this case ions rather than electrons are emitted, but the role played in providing a space charge is the same. The use of such cathodes, together with the simple quantitative theory of their operation, provides a means of extrapolating to the "intrinsic electric strength" of liquids; i.e., the electric strength in the absence of cathode effects.

X7. Applications of Electrostatic Control of Electric Charges Furnished by Glow Discharge. Pierre Toulon.—The combination of a sharp pointed needle at high voltage, facing the center of a hole in a conductive mask, produces a stream of charged particles capable of jumping over a plate at appreciable distance if a voltage of opposite sense is applied. The flow of charged particles may be electrostatically controlled by a grid, or simply by a ring. The paper describes the characteristics of amplifiers or modulators with one or a plurality of control grids having similar functions as in high vacuum tubes. In some devices requiring a great multiplicity of independent tubes, the cost is very low, since the system does not require a vacuum, and the needles, the mask, and the grids may be made in the form of a sheet, in multiples of thousands side by side. A large television screen uses this principle. The process is only applicable for low currents and low frequencies. Diodes are also constructed by facing a high voltage needle toward two electrodes, symmetrically disposed, affecting the switching of flow of charged particles for small voltage differences.

X8. Whirling Movements of the Conductor as a Result of the Interaction between Electric and Magnetic Fields. OLEG YADOFF, *Columbia University*.—In our previous reports we described the effect of the influence of an electric field on an electric current as well as the phenomenon which derived from this effect and consists of the production of electric turbulences in a fluid medium; we explained the latter as the result of the interaction between electric and magnetic fields. The following data on the observations of a new effect confirm our earlier hypothesis. If the electric field concentrically acting towards the magnetic field which accompanies the electric current passing along the axis of a closed system is gradually increased, a point is reached when the interaction between the electric and the magnetic fields sets in motion the conductor situated along the axis. The conductor rotates in a whirling movement, forming a regular pattern at various frequencies $f_1, f_2, f_3, \cdots f\rho$. When the conductor is incandescent, the whirling movement acquires a bright, pictorial form which can easily be photographed and which assumes the appearance of electromagnetic lenses. The shape of the whirling movement of the conductor corresponds to the equation of the projection along the x axis:

$$\frac{d^2r}{dt^2}=-\frac{1}{2}\frac{e}{m}r\left[\frac{e}{m}H_x^2+E_x''\right];\ \frac{d\theta}{dt}=-\frac{e}{m}H_x \text{ and } \frac{d^2x}{dt^2}=-\frac{e}{m}E_x'.$$

X9. Ion Concentrations in Intense Discharges from Stark Effect Broadening. H. N. OLSEN* AND W. S. HUXFORD, *Northwestern University*.—Broadening of the H_α and H_β lines produced by ionic fields in condensed flash discharges is recorded by means of a photocell and synchroscope. A trace of hydrogen is used as a spectroscopic probe in argon and neon. The Holtsmark[1] theory as applied by Verweij[2] is used to determine ion fields as a function of time during the flash. The error of this method is estimated at less than 10 percent. Calculated values of ion concentration are plotted against time. A maximum concentration occurs about seven microseconds after initiation of the discharge at pressures of about 75 mm Hg. The variation of ion concentration with time is compared with oscilloscope traces of spark lines, arc lines, and continuum. Bremsstrahlung processes are considered to be the chief sources of continuous radiation in the afterglow.

* Now at Linde Air Products Company, Tonawanda, New York.
[1] J. Holtsmark, Ann. Physik, **58**, 577 (1919).
[2] S. Verweij, Pub. Astron. Inst. Univ. Amstr., No. 5 (1936).

X10. Radiation Loss by Electrons in Large Orbits.* DALE R. CORSON, *Cornell University*.—The energy loss by electrons in a one-meter radius synchrotron orbit has been measured for electron energies between 225 and 318 Mev and found to be in close agreement with the classical radiation value.[1] The energy loss is measured by observing the rate at which the orbit shrinks when the radiofrequency accelerating voltage is removed. To measure this rate the visible light is focused on a grid placed before an electron multiplier tube. When the orbit shrinks the spot of light moves across the grid, modulating the output of the multiplier. Distances are calibrated by intercepting the electron beam at different orbit radii with the synchrotron target. Orbit shrink rates are also measured by observing the x-ray production times for different target positions. The most sensitive measure of energy loss, and one that is independent of the radial variation of the magnetic field, is the determination of the point on the back side of the magnetic cycle where the orbit is in equilibrium when the rf accelerating voltage is removed. Determination of H and $\dot{H}$ throughout the magnetic cycle is made with the aid of a coil which rotates synchronously (30 cycles per sec) with the magnetic field.

* Supported in part by the ONR.
[1] J. Schwinger, Phys. Rev. **75**, 1912 (1949).

X11. Ultraviolet Radiation from the Cornell Synchrotron.* P. L. HARTMAN AND D. H. TOMBOULIAN, *Cornell University*.—Preparatory to contemplated investigations in the vacuum ultraviolet region, the intensity distribution of the radiation from the synchrotron is being studied in the spectral range which extends from 4500A to 2200A. In contrast to the work of Elder, Langmuir, and Pollock[1] the photographic technique is being utilized in anticipation of its use for measurements below the region of quartz transmission. Exposures are obtained by the use of a synchronized shutter which accepts light only over a 3° range out of the 90° acceleration interval. By varying the phase of the shutter, this scheme makes it possible to examine the radiation from electrons whose energies lie in a narrow band centered about a specified value of the energy. Sepctra have been obtained for mean electron energies which varied in steps from about 40 Mev to the peak energy of 318 Mev. Above 100 Mev, the spectral region covered by the present measurements shows little variation in the energy distribution of the emitted light. Problems in photometry and agreement with existing theories will be discussed. The work has enjoyed the generous assistance of many members of the staff associated with the synchrotron.

* This work supported in part by the ONR.
[1] Elder, Langmuir, and Pollock, Phys. Rev. **74**, 52 (1948).

SATURDAY AFTERNOON AT 2:00

NBS, East Building Lecture Room

(R. J. SEEGER presiding)

Fluid Dynamics and Ultrasonics

XA1. Ultrasonic Dispersion and Absorption in the Vapors of *Cis-* and *Trans-*Dichloroethylene.* J. C. HUBBARD AND D. SETTE,† *The Catholic University of America*.—A study of ultrasonic velocity and absorption in the liquids, *cis-* and *trans-*dichloroethylene has been published by one of the authors[1] and it was evident that measurements of ultrasonic propagation in their vapors would be of great interest. Measurements have been obtained of ultrasonic velocity and absorption at 32°C and at pressures from 1.2 cm to about 25 cm of mercury, giving f/p values of 1.27 to 125 Mc/atmos. Indications are found for two f/p regions of dispersion in each vapor, one being common to both vapors with the relaxation mid-point value of f/p at 3.5 Mc/atmos, the other for *cis*- at 30 Mc/atmos and for *trans*- at 90 Mc/atmos. Values of Cv/R range from 7.5 to 3.5 for the *cis*- and from 8 to 4 for the *trans*-. Maxima of molecular absorption for the former are at 3.44 and 28.7, for the latter at 3.46 and 84 Mc/atmos.

* Supported by ONR.
† Instituto di Ultracustica, Rome, Italy. At present at the Catholic University of America.
[1] D. Sette, J. Chem. Phys. **19**, 1337–1341 (1951).

XA2. Theory of the Mach-Zehnder Interferometer. F. D. Bennett and G. D. Kahl, *Ballistic Research Laboratories.*—The vector theory of the ideal, planar, Mach-Zehnder interferometer[1] is extended to include three-dimensional models based on geometry of the ellipsoid. Necessary and sufficient conditions for production of white light fringes are determined, and the path difference formula governing interference is developed as in the planar case. Expressions for fringe width and orientation are found and the effects of various source points determined. The problem of optimum source is found reducible to that already treated for the planar interferometer. The effect of a thick plane-parallel plate on a parallel beam is studied. An actual thick plate interferometer is represented as an ideal, ellipsoidal interferometer with the effects of thick plates linearly superposed. Conditions are investigated for obtaining perfect plate compensation; these plus the choice of "vertical" fringes reduce the ellipsoidal interferometer to planar form. Tests for alignment of a thick plate instrument are suggested. Finally terms accounting for thick windows and compensating chambers are considered and requirements developed for compensation in the BRL pressure-temperature controlled range.

[1] F. D. Bennett, J. Appl. Phys. **22**, 184 (1951); also BRL Report No. 731, September 1950.

XA3. Scattering by a Semi-Infinite Cone. K. M. Siegel and H. A. Alperin, *University of Michigan.*—Recently the authors obtained the differential scattering coefficient for the scattering of scalar (sound) waves by a semi-infinite cone.[1] In that paper this solution is compared with the electromagnetic solution obtained by Hansen and Schiff.[2] For purposes of computation the reduction of the algebraic results can be facilitated by the introduction of a characteristic length (e.g., the distance from the vertex of cone to observer). It is then shown that the results are insensitive to the characteristic length so chosen. The differential scattering coefficients obtained by scalar and vector theory, for axially symmetric backscattering from a 20° cone and from a 30° cone, are then analyzed and compared.

[1] "Scattering by a Semi-Infinite Cone," UMM 87, Willow Run Research Center, University of Michigan (January 1952).
[2] "Theoretical Study of Electromagnetic Waves Scattered from Shaped Metal Surfaces," Quarterly Report No. 4, Microwave Laboratory, Stanford University.

XA4. Low Velocity Detonation of Certain Primary Explosives. R. H. Stresau,* *U. S. Naval Ordnance Laboratory.*—Under conditions of very high loading density and high radial confinement, and when marginally initiated, lead azide and mercury fulminate were found to react in an unusual manner. The propagation rate of the reaction was found to be between 1400 and 1700 meters per sec as contrasted with a detonation velocity of over 5000 meters per sec for the same materials at the same loading densities when more vigorously initiated. The interior of a hole through which such a reaction has passed is smooth and lustrous, while one through which a normal detonation has passed is black and riddled with longitudinal cracks. Experiments with various confining media and column diameters show that these have little, if any, effect upon the propagation velocity but make adjustments of other conditions necessary in order to cause this type of reaction. Possible mechanism of this type of reaction are discussed.

XA5. Recent Air Shock Velocity Measurements Near Detonating Explosives. J. Savitt and R. H. Stresau, *U. S. Naval Ordnance Laboratory.*—Previously reported small scale measurements[1] of ionized air shock velocities near detonating explosives have been extended to include measurements made with large numbers of different explosive systems. By confining the explosives and the air shocks in heavy walled cylindrical metal tubes, one-dimensional progation was approximated. By assuming a linear relationship between the velocity of the explosive particles in the detonation and the mass of explosive between the detonation front and these particles, a simple relationship between the air shock velocity V and the distance to the original explosive air-interface Y, is suggested by applying the principle of momentum conservation. It is found that $y=(\epsilon/\rho)[(V_0-V)^2/V]$, where V_0 is the initial air shock velocity, ρ is the undisturbed air density, and ϵ is a constant dependent upon the explosive. This relationship is found to be in good agreement with the observations.

[1] R. H. Stresau and J. Savitt, Chicago A.P.S. Meeting, October 1951.

XA6. Vibrational Energy Lag in Shock Waves.* Wayland Griffith, *Princeton University.*—Relaxation effects in molecular gases due to the failure of vibrational modes to follow the rapid increase of temperature in a shock front have been observed with a shock tube and interferometer. The pressure and density behind the shock don't attain the values predicted by the ordinary Rankine-Hugoniot relations instantaneously because practically no excitation of vibrational levels can occur during the few collisions in the shock front. The region of vibrational adjustment is very large compared to the thickness of the shock front. For example, in CO_2 at a pressure of $\frac{1}{5}$ atmos a shock of pressure ratio 2:1 is found to be 0.1 inch thick. This is in agreement with data on the relaxation time of CO_2 obtained previously by another method.[1] Comparison with an approximate theory for the adjustment process given by Bethe and Teller[2] will be discussed.

* This work was supported by an ONR contract.
[1] W. Griffith, J. Appl. Phys. **21**, 1319 (1950).
[2] H. A. Bethe and E. Teller, "Deviations from Thermal Equilibrium in Shock Waves," recently reissued by the University of Mich. Engr. Research Inst.

XA7. Luminescence Produced as a Result of Intense Ultrasonic Waves.* V. Griffing and D. Sette,† *Catholic University of America.*—Luminescence has been observed when water saturated with CCl_4 is subjected to intense ultrasonic waves. Luminescence occurs only when cavitation is also observed. Observations were made using various dissolved gases, e.g., argon, nitrogen, oxygen, carbon dioxide, and sulfur hexafluoride. In every case luminescence occurred only when chemical reactions took place; the estimated intensity of luminescence and the amount of chemical reaction went qualitatively parallel. The experiments were made at 2 mc, 1 mc and 600 kc with acoustic intensities of approximately 6.5, 2, and 1 watt/cm^2. Observations were made on cavitation in other liquids, but no luminescence or chemical effects were observed. It seems, therefore, that the origin of luminescence is to be found in the chemical reactions occurring during cavitation.

* Supported by ONR.
† From Instituto di Ultracustica, Rome, Italy. At present at the Catholic University of America.

XA8. Ultrasonic Automatic Viscosity Measurement. STANLEY R. RICH AND WILFRED ROTH.—Ultrasonic longitudinal waves are produced in a magnetostrictive resonant element by impulse excitation. Shear waves are excited in the liquid in contact with a portion of the member. An electronic analog computer automatically solves the equation relating shear wave propagation to liquid viscosity presenting the solution directly and continuously on an indicating meter calibrated in centipoises×g/cc. Theory of the basic phenomenon and of the computer is discussed. Results are presented including: viscosity of Newtonian liquids *versus* temperature, viscosity of blends of Newtonian liquids; viscosity measurements during polymerization of high polymers; during clotting of whole blood; during gelation of gelatin solutions; during curing of thermosetting resins.

Post-Deadline Papers, If Any

SATURDAY AFTERNOON AT 2:00

Wardman Park, Burgundy Room

(M. DEUTSCH presiding)

Positronium; Pair Creation

Y1. Conservation of Energy in Three-Quantum Annihilation.* R. SIEGEL AND S. DE BENEDETTI, *Carnegie Institute of Technology*.—The triple-coincidence technique previously described[1] has been used to continue a study of the three-quantum annihilation of positrons and electrons. Three large NaI(Tl) scintillation counters were arranged in a plane about a source of positronium, which was obtained by stopping fast positrons from Na^{22} in a dense atmosphere of SF_6. The three counters were connected in fast coincidence ($\tau \sim 10^{-7}$ sec) and differential pulse height selectors were used to study the energies of the coincident rays. According to the conservation laws, the three gamma-rays of annihilation have energies determined by the angles between the counters, so that changes in the arrangement of the counters cause changes in the energies of the coincident rays. The heights of the coincident pulses were studied for different angular arrangements. From the analysis of the data it was found that the energies of the three-quantum annihilation rays agreed with the values predicted by energy-momentum conservation. The experimental data will be presented.

* Supported by the AEC.
[1] S. De Benedetti and R. Siegel, Phys. Rev. **85**, 371 (1952).

Y2. An Investigation of the Three Photon Annihilation of the Positron. RICHARD S. STONE, *Rensselaer Polytechnic Institute*.*—By use of a triple coincidence gamma-ray spectrometer with a similar geometry to that used by Rich,[1] the three-photon annihilation of the positron has been detected in brass and studies of the angular distribution of the three gamma-rays have been made by moving two of the counters in the plane. Initially in several Cu^{64} runs, the ratio of the counting rate in the plane to that out of the plane was approximately 2:1. At the conclusion of a typical 24-hour run, this ratio was approximately 10:1. The counting rate out of the plane varied as the cube of the source strength indicating that triple coincidences due to Compton scattering are relatively few. The three-photon annihilation explains the higher counting rate in the plane. Distribution functions for the probability that, given a photon of energy k, the other two photons would share the remaining energy equally were calculated from the work of Ore and Powell.[2] The experimental data will be compared to these theoretical curves.

* Supported in part by the AEC and by the Rensselaer Polytechnic Institute Research Fund.
[1] J. A. Rich, Phys. Rev. **81**, 140 (1951).
[2] A. Ore and J. L. Powell, Phys. Rev. **75**, 1696 (1949).

Y3. Electrodynamic Corrections to the Fine Structure of Positronium. A. KLEIN AND R. KARPLUS, *Harvard University*.—A Lorentz-invariant wave equation for the bound states of the electron-positron system has been derived from the formalism of Schwinger.[1] This equation has been used in conjunction with a four-dimensional perturbation theory[2] to obtain the splitting, correct to order $\alpha^3 Ry$, of the 1^1S-1^3S ground-state doublet of positronium. The perturbations can be divided meaningfully into two sets according to whether all intermediate states contain an electron-positron pair or some do not. The first of these consists of the Breit interaction, the exchange of two photons, and self-energy effects (anomalous moments); the second, which is specific to the system considered, includes one- and two-photon virtual annihilation of the original pair. The required accuracy is achieved by employing a wave function which is the first-order solution of the equation for the Coulomb plus retarded Breit interactions. The energy difference thus found is

$$(7/6)\alpha^2 Ry_\infty\{1-(\alpha/\pi)[(41/21)-(3/7)\ln 2]\} = 2.033\times 10^5 \text{ Mc/sec.}$$

The agreement of this result with experiment will be discussed.

[1] J. Schwinger, Proc. Natl. Acad. Sci. **37**, 452 (1951).
[2] E. E. Salpeter, Bull. Am. Phys. Soc. **27**, No. 1 (1952).

Y4. Quenching of the Three-Quantum Annihilation from Positronium by a Magnetic Field.* J. WHEATLEY AND D. HALLIDAY, *University of Pittsburgh*.—We have measured the quenching of the three-quantum annihilation from positronium[1] by observing the change in the triple coincidence rate with magnetic field. Our detection apparatus is similar to that of DeBenedetti and Siegel.[2] The experimental arrangement is as follows: The three scintillation detectors are magnetically shielded and placed at 120° to one another, their three axes and the source lying in a plane. The source, 0.01 mc Na^{22}, is mounted on a Zapon film and placed in a tube filled with sulfur hexafluoride[3] at 300 pounds/in^2. The magnetic field is perpendicular to the plane of the counters. Preliminary data are in agreement with Deutsch's value for the ground state splitting. The fraction of the three-quantum annihilation not quenched approaches the value one-half for strong fields.

* Work done in the Sarah Mellon Scaife Radiation Laboratory and assisted by the joint program of the ONR and AEC and the Research Corporation.
[1] M. Deutsch and E. Dulit, Phys. Rev. **84**, 601 (1951).
[2] S. DeBenedetti and R. Siegel, Phys. Rev. **85**, 371 (1952).
[3] Suggested to us by DeBenedetti and Siegel.

Y5. Complex Time Decay of Positrons Annihilated in Condensed Materials. R. E. BELL AND R. L. GRAHAM, *Chalk River Laboratory.*—The time distribution of positron annihilations in condensed materials is being studied. A lens spectrometer focuses 220-kev positons which have first passed through a thin stilbene crystal, either (1) directly onto a thick diphenylacetylene crystal or (2) onto a 1-mm layer of the test material placed immediately over this crystal, which then counts annihilation quanta. Condition (1) gives the prompt reference curve for the coincidences between the two phosphor crystals (resolving time $2\tau_0=1.8\times10^{-9}$ sec) and (2) gives coincidences delayed by the time required for positons to annihilate in the test material. Aluminum, gold, NaCl, graphite, diamond, and crystalline quartz yield delayed coincidence resolution curves consistent with a single mean life ranging from 1.2×10^{-10} to 4×10^{-10} sec. Fused quartz, polystyrene, polyethylene, Teflon, and others display two decay components, one of mean life $\sim3\times10^{-10}$ sec ($\sim2/3$ of the decays) and the other of $\sim2\times10^{-9}$ sec ($\sim1/3$ of the decays). A few substances, e.g., fused B_2O_3, are intermediate between the two classes. The fact that positons decay differently in crystalline than in fused quartz suggests that any explanation of the present results will emphasize the structure of the materials.

Y6. Positron-Electron Scattering. ARTHUR ASHKIN AND W. M. WOODWARD, *Cornell University.*—Measurements are being made of the differential cross section for the scattering of positrons by atomic electrons as a function of positron energy E, and the fractional-energy transfer v. The apparatus is similar to that used by Page* for electron-electron scattering. A uniform magnetic field is used to define the incident positron energy and to analyze the scattered particles. Two Geiger counters in coincidence record the scatterings. Co^{56} is used as a source of positrons and a thin plastic film as a scattering foil. In practice we measure the ratio of positron-electron scatterings to electron-electron scatterings for the same E and v. This ratio we can determine to greater accuracy than the absolute cross section. Our experiment does yield absolute cross sections at somewhat reduced precision. For $E=600$ kev and $v=1/2$ the theoretical ratio of the differential cross section of electrons to positrons is 3.07. This is obtained using the Moller and Bhabha formulas. The measured value at this point is $3.09\pm.22$. At this energy the measured absolute cross section are about 6 percent low presumably because of multiple scattering.

* Lorne A. Page, Phys. Rev. **81**, 1062 (1951).

Y7. Internal Pair Creation in Mg^{24}. STEWART D. BLOOM, *Institute for Nuclear Studies, University of Chicago.*—The positron spectra from the internal pair creation of the two γ-rays ($\gamma_1=2.76$ Mev, $\gamma_2=1.38$ Mev) resulting from the β^- decay of Na^{24} have been observed, and the internal pair creation coefficients (I_1, I_2) measured, using a double lens β-ray spectrometer.[1] According to Table I the following two

TABLE I. Observed and theoretical (see reference 2) values of I_1 and I_2

	Observed value $\times10^4$	Theoretical values $\times10^4$				
I_1	6.69 ± 0.20	11.20($E1$)	6.80($E2$)	4.62($E3$)	5.36($M1$)	3.45($M2$)
I_2	0.58 ± 0.14	1.87($E1$)	0.57($E2$)	0.19($E3$)	0.25($M1$)	0.07($M2$)

possibilities characterize both γ_1 and γ_2: (1) Pure E_2; (2) mixture of $E1$, $E3$, and $M2$. In the case of γ_1 the theoretical energy spectrum for a pure $E2$ transition[2] corresponds very closely to the observed energy spectrum. This is not true for any combination of $E1$, $E3$, and $M2$. Thus γ_1 would seem to correspond to a pure $E2$ transition. Since the value of I_2 and the $\gamma_1-\gamma_2$ angular correlation[3] are both characteristic of $E2$ transitions. γ_2 would also seem to correspond to a pure $E2$ transition.

[1] H. M. Agnew and H. L. Anderson, Rev. Sci. Instr. **20**, 869 (1949).
[2] M. E. Rose, Phys. Rev. **76**, 678 (1949).
[3] E. L. Brady and M. Deutsch, Phys. Rev. **74**, 1541 (1948).

Y8. Masses of the Stable Tellurium Isotopes from the Microwave Spectrum of TeCS.* G. SILVEY, W. A. HARDY, AND C. H. TOWNES, *Columbia University.*—The microwave spectrum of TeCS has been examined in the rotational transitions $J=6\rightarrow7$ and $J=7\rightarrow8$. Seven isotopes were found and from their absorption frequencies mass ratios have been calculated. The masses of Te^{124} and Te^{128} have been taken as given correctly by a Bohr-Wheeler type formula and the masses of the other isotopes are given in Table I, together with the masses predicted by the formula. The odd-even mass variation is approximately 2.5 milli-mass units. The Te=C bond distance is 1.904A and the C=S distance 1.557A. No quadrupole hyperfine structure was detected. The TeCS was prepared by arcing graphite-tellurium rods in CS_2, and purified by distillation at $-78°C$.

TABLE I.

Isotope	B_{000} in Mc	Experimental mass	Mass from formula
130	1559.9306	$129.9646\pm.0005$	129.9652
128	1565.7021	127.9609	127.9609
126	1571.6519	$125.9579\pm.0005$	125.9575
125	1574.6908	$124.9585\pm.0005$	124.9571
124	1577.7904	123.9550	123.9550
123	1580.9199	$122.9578\pm.0012$	122.9551
122	1584.1216	$121.9538\pm.0005$	121.9535

* Work supported by the AEC.

Y9. Mass Spectra of Isotopic CO_2 Molecules.* F. S. STEIN,† *University of Buffalo.*—The mass spectra of a 1:1 mixture of $C^{13}O_2$ and $C^{12}O_2$ molecules were determined using a Consolidated-Nier (dual-collector) mass spectrometer. Magnetic scanning was effected through the use of a gear-reduction motor connected with the analyzer magnet. Samples were evolved from C^{13} enriched $CaCO_3$ and purified. Sample pressures were chosen to give measured ratios practically independent of small pressure changes. Appropriate corrections were applied for the presence of residual peaks, oxygen isotopes, space charge in the ionization chamber, and the finite accelerating voltage used (1250 V.). The corrected ratios are as follows: $(C^{13}O/C^{12}O)/(C^{13}O_2/C^{12}O_2)=0.948$ and $(C^{13}/C^{12})/(C^{13}O_2/C^{12}O_2)=1.022$. The corresponding values measured by V. H. Dibeler *et al.*[1] using a 180° mass spectrometer and electrostatic scanning are 0.949 and 0.961. O. A. Schaeffer[2] obtained a value of 1.007 for the latter ratio but concluded from theoretical considerations that this ratio is unity in the absence of experimental errors. It is concluded from this investigation that this latter ratio is actually greater than unity.

* Aided in part by a grant from the American Cancer Society.
† Now at the Westinghouse Research Laboratories, East Pittsburgh, Pennsylvania.
[1] Dibeler, Wells, and Reese, Phys. Rev. **79**, 223 (1950).
[2] O. A. Schaeffer, J. Chem. Phys. **18**, 1501 (1950).

Y10. Atomic Masses and Nuclear Shell Structure at 20 and 28 Neutrons and Protons.* THOMAS L. COLLINS, ALFRED O. NIER, AND WALTER H. JOHNSON, JR., *University of Minnesota.*—Measurements of atomic masses with the Minnesota double-focusing mass spectrometer now include almost every stable isotope from S^{32} to Zn^{70}. In addition, the atomic masses of many radioactive isotopes in this region can be computed from nuclear reaction energies, giving a total of 81 masses between mass numbers 31 and 70. A fit of the semi-empirical Wigner mass formula to this data discloses the existence of discontinuities in the binding energy surface at 20 and 28 neutrons and protons. The discontinuities are primarily changes in slope of the surface rather than discrete jumps in the binding energy.

* Research supported by joint program of the ONR and AEC.

Y11. Nuclear Masses and the Electron Mass. ENOS E. WITMER, *University of Pennsylvania.*—The mass of any nucleus or elementary particle in any state may be written as Mm, where m is the rest mass of the negative electron. The experimental data shows that in many cases M is an integer or rational number, which in the usual form of a fraction in its lowest terms is p/q. We will assume that M is always a rational number. This statement is saved from redundancy by the large number of cases where q is one or a very small integer. The writer has justificably stressed the case when q is eleven. For the neutron, proton, and the nuclei of C^{12} and O^{16}, M is 14709/8, 20197/11, 21868, and 29148, respectively. For $Z\leqslant 10$ the most abundant isotope for each Z has an M which is within 0.3 of an integer and in all except a few cases within 0.1. There are six nuclei in this interval with M integral. There are also a number of pairs of isotopes for which the M differences are integral. The excited states of nuclei exhibit similar regularities. *Thus m appears to be the natural unit of mass for nuclei and elementary particles.*

SATURDAY AFTERNOON AT 2:00

Shoreham, Main Ballroom

(A. C. HELMHOLZ presiding)

Scattering of Protons and Neutrons

YA1. Analysis of $p-T$ Scattering. J. S. MCINTOSH, R. L. GLUCKSTERN, S. SACK, AND B. E. FREEMAN,* *Yale University.*†—A phase shift analysis of $p-T$ scattering data from 1−3.5 Mev[1] was undertaken. S and P waves fit the data. However, an infinite number of S wave phase shift pairs ($^1K_0$, $^3K_0$) proved possible. For each S wave pair two satisfactory p wave pairs ($^1K_1$, $^3K_1$) exist, one of which contains values of $^1K_1$ larger than expected for purely potential scattering. The variation of these "resonant" values of $^1K_1$ with energy could be consistent with a possible resonant state[2] of He^4 of level width about 1 Mev at a proton energy of about 4 Mev. An analysis[3] of $p-D$ data[4] indicates that D waves are required to fit lower angle data allowing only certain regions of values for $^2K_0$ and $^4K_0$. Attempts to analyze $p-D$ data without D waves indicate desirability of caution regarding omitting D waves since low angle data are lacking here.

* Now at the Los Alamos Scientific Laboratory.
† Assisted by the joint program of the ONR and AEC.
1 Hemmendinger, Jarvis, and Taschek, Phys. Rev. 76, 1137 (1949). Claasen, Brown, Freier, and Stratton, Phys. Rev. 82, 589 (1951).
2 Argo, Gittings, Hemmendinger, Jarvis, and Taschek, Phys. Rev. 79, 929 (1950).
3 C. Critchfield, Phys. Rev. 73, 1 (1948).
4 Sherr, Blair, Kratz, Bailey, and Taschek, Phys. Rev. 72, 662 (1947).

YA2. Inelastic Proton Scattering from B^{10}.* W. W. BUECHNER, C. P. BROWNE, M. M. ELKIND, A. SPERDUTO, H. A. ENGE, AND C. K. BOCKELMAN, *M.I.T.*—Thin targets of B^{10} have been bombarded with 7-Mev protons from the ONR electrostatic accelerator. Protons scattered from the targets in a direction at right angles to the incident beam have been analyzed with a 180-degree magnetic spectrograph. In addition to an elastically scattered group, five additional groups have been observed. These indicate energy levels in B^{10} at 0.71, 1.74, 2.15, 3.58, and 4.76 Mev. These values are in good agreement with those obtained by Fay Ajzenberg[1] from the $Be^9(d, n)B^{10}$ reaction.

* This work has been supported by the joint program of the ONR and AEC.
1 Fay Ajzenberg, Phys. Rev. 82, 43 (1951).

YA3. Energy Levels Resulting from 8-Mev Protons on Be^9, C^{12}, N^{14}, S^{32}.* J. S. ARTHUR, A. J. ALLEN, R. S. BENDER, H. J. HAUSMAN, C. J. MCDOLE, L. M. DIANA, K. B. RHODES, AND R. A. BARJON, *University of Pittsburgh.*—Eight-Mev protons were used in the scattering project to investigate reactions in thin targets of Be^9, nylon, and S^{32}. The 2.42-Mev level in Be^9 from the $Be^9(p, p')Be^9$ reaction was observed. Alpha-peaks were also observed. A 0.2-mil nylon target was bombarded at 90° and 150°. Proton groups were observed corresponding to O^{16}, N^{14}, and C^{12} elastic peaks; energy levels in N^{14} at 2.32, 3.80, and 3.96 Mev; and the C^{12} energy level at 4.47 Mev. In addition to the elastic group, seven inelastic proton groups were observed in S^{32}. These correspond to excited levels in S^{32} at 2.25, 3.85, 4.33, 4.57, 4.74, 5.05, and 5.35 Mev.

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

YA4. Determination of the Angular Distribution and Absolute Differential Cross Section of the $C^{12}(p, p)C^{12}$ Reaction.* H. L. JACKSON, A. I. GALONSKY, F. J. EPPLING, R. W. HILL, E. GOLDBERG,† AND J. R. CAMERON,† *University of Wisconsin.*—The $C^{12}(p, p)C^{12}$ differential cross section was measured from 0.4 to 4.35 Mev using propane, ethylene, and methane targets. Observations were made at 102°, 124°, 146°, and 168°. The proton beam was introduced into the scattering chamber through a differential pumping column to avoid the necessity of a foil. A preliminary examination of the data qualitatively supports the level assignment[1] based on the work of Williamson and Goldhaber. A quantitative analysis is in progress.

* Work supported by the AEC and the Wisconsin Alumni Research Foundation.
† AEC Predoctoral Fellow.
1 H. L. Jackson and A. I. Galonsky, Phys. Rev. 84, 401 (1951).

YA5. The Angular Distributions of the $C^{12}(p, p')C^{12*}$ $Q=-4.45$ Mev and the $Mg^{24}(p, p')Mg^{24*}$ $Q=-1.38$-Mev Reactions Using a NaI Scintillation Counter.† H. E. GOVE AND H. F. STODDART, *M.I.T.*—The NaI scintillation counter described in another abstract has been used to measure the angular distributions of inelastically scattered protons from C^{12} and Mg^{24} leaving the nuclei in their first excited state. The proton bombarding energy was 7.3 Mev. The results have been fitted to Legendre polynomial expansions and indicate terms as high as six in the carbon case. The two distributions are notably different which is interesting in view of the fact that, in both cases, the spin of the target nucleus is zero, even parity, and that of the residual Mg^{24} nucleus, in the first excited state, is two, even parity, while that of the first excited state of C^{12} is also predicted[1] to be two, even parity. However, both distributions are assymmetric about 90° indicating that at least two levels of different parity are involved in the compound nuclei (Al^{25} and N^{13}) about which nothing is known. This makes any theoretical analysis rather complicated.

† Supported in part by the joint program of the AEC and ONR.
[1] R. R. Haefner, Revs. Modern Phys. 23, 228 (1951).

YA6. Excited States of Mg^{24}, Cr^{52}, and Mn^{55}.* H. J. Hausman, A. J. Allen, J. S. Arthur, R. S. Bender, C. J. McDole, L. M. Diana, K. B. Rhodes, and R. A. Barjon, *University of Pittsburgh*.—The reactions $Mg^{24}(p,p')Mg^{24}$, $Cr^{52}(p,p')Cr^{52}$, and $Mn^{55}(p,p')Mn^{55}$ have been investigated by means of magnetic analysis of the proton groups emitted from thin targets. A magnetic analyzed beam of 8-Mev protons from the 47-in. University of Pittsburgh cyclotron were used as incident bombarding particles. Three of the twelve proton groups observed from the bombardment of a thin natural magnesium target have been assigned to excited states of Mg^{24} at 1.38 Mev and a doublet at 4.14 Mev. Identification of these states was obtained from the $Al^{27}(p,\alpha)Mg^{24}$ reaction. Six proton groups have been tentatively assigned to excited states in Mg^{25}. In the region of excitation from zero to 6 Mev, fifteen proton groups were observed from the bombardment of natural chromium. Assignment of the energy levels in chromium will be made. An assignment of 13 excited states in Mn^{55} has been made in the region of excitation from zero to 5.5 Mev. Observations of the proton groups from the above reactions were made at laboratory angles of 150° and 90° to the incident beam.

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

YA7. Energy Levels in Al^{27} and Na^{23} Using a Scintillation Spectrometer for Heavy Particles.* H. F. Stoddart and H. E. Gove, *M.I.T.*—A heavy particle scintillation spectrometer of moderate resolution (2 percent full width at half maximum for 14.5-Mev deuterons) has been developed for use in conjunction with scattering experiments at the M.I.T. cyclotron. A 1/16 inch thick plate of NaI(Tl) crystal is used as the scintillator and the light is directed onto the face of an RCA 5819 photomultiplier by an aluminum reflector. The ratio of pulse height to incident energy is found to be constant to better than 4 percent in the region of 0–7-Mev proton energy. With this counter energy levels of Al^{27} were found using inelastic proton scattering from thin aluminum targets at 0.84, 1.01, 2.23, 2.77, 3.03, 3.71, 4.00, 4.47, 4.60, 4.87, and 5.43 Mev. Similar measurements with a sodium target give 2.10, 2.37, 2.69, 3.01, 3.70, 3.92, and 4.45 Mev as levels of Na^{23}. A carbon target shows only one level in the 0–6.5-Mev region, that of C^{12} at 4.45 Mev. Additional experiments using this counter are described in other abstracts.

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

YA8. Multiple Scattering of High Energy Protons in Photographic Plates.* Martin J. Berger, *University of Chicago*.—A determination has been made of the multiple scattering of protons with energies $E=337\pm1$ Mev and $E=218\pm2$ Mev in photographic emulsions. Ilford G-5 plates were used for this purpose that had been exposed to the proton beam of the Berkeley cyclotron. The results may be summarized in terms of the customary scattering constant $K=10s^{-\frac{1}{2}}\bar{\alpha}pv$, where p and v are the momentum and velocity of the scattered particle (pv in Mev), s is the length of the cells into which the analyzed tracks are divided (in microns), and $\bar{\alpha}$ is the mean angular deflection (chord-angle) per cell (in degrees). In the range from $s=250\mu$ to $s=750\mu$, K was found to increase only slightly. A weighted average of the results in this range of cell lengths gives $K=26.3\pm1.0$ at $E=337$ Mev, and $K=26.9\pm1.3$ at $E=218$ Mev. When a cutoff is applied to the chord-angles, whereby deflections greater than four times the mean are eliminated, the corresponding scattering constants are found to be K (cutoff) $=24.5\pm0.8$ at $E=337$ Mev, and K (cutoff) $=25.2\pm1.0$ at $E=218$ Mev. The experimental results are in fair agreement with the predictions of the multiple scattering theories of Molière, Snyder, and Scott, and a proposed extension of the theory of Goudsmit and Saunderson.

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

YA9. The Scattering of 10-Mev Deuterons by H^3 and by He^3. A. H. Armstrong, J. C. Allred, A. M. Hudson, R. M. Potter, E. S. Robinson, L. Rosen, and E. J. Stovall, Jr., *Los Alamos Scientific Laboratory*.*—The differential cross sections for 10-Mev deuterons scattered by H^3 and by He^3 have been determined at 43 angles between 29° and 140° in the center-of-mass system. A multiplate camera[1] was used; 162,000 tracks were counted. The identity of the cross sections above 50° for this set of mirror interactions is consistent with present evidence for the equality of $n-n$ and $p-p$ forces. Below 50° the two curves diverge to an extent which can be attributed to the increased Coulomb scattering by He^3. There is considerable evidence of deuteron disintegration in both interactions. The shape of the curve above 50° may be inferred from the following values of differential cross section in millibarns per steradian at the corresponding center-of-mass angles in degrees: 87 (50°); 25 (60°); 20 (65°); 37 (75°); 69 (85°); 86 (98°); 68 (110°); 39 (120°); 26 (130°); 40 (140°). The characteristics of these angular distributions may perhaps lend themselves to eventual interpretation by some kind of stripping theory.[2,3]

* Work performed under the auspices of the AEC.
[1] Allred, Rosen, Tallmadge, and Williams, Rev. Sci. Instr. 22, 191 (1951).
[2] S. T. Butler, Proc. Roy. Soc. (London) 208, 559 (1951).
[3] R. Huby and H. C. Newns, Phil. Mag. 42, 1442 (1951).

YA10. Scattering of Fast Neutrons by Deuterons.* M. Walt,† A. Okazaki, and R. K. Adair, *University of Wisconsin*.—The difference in the total neutron cross section of hydrogen and deuterium was measured at nine neutron energies between 264 kev and 3 Mev, and the angular distribution of neutrons scattered by deuterons was measured at seven neutron energies from 220 kev to 2.5 Mev. Fast neutrons were produced by the $Li^7(p,n)Be^7$ and $H^3(p,n)He^3$ reactions using protons from an electrostatic generator. Samples of H_2O and D_2O in brass containers were placed between the neutron source and a hydrogen recoil counter, and the cross section difference was determined by comparing the transmissions of the two samples. The values of $\sigma_H-\sigma_D$ varied from 5.25 ± 0.15 barns at 264 kev to 0.18 ± 0.03 barn at 3 Mev. The angular distribution of scattered neutrons was determined by observing the pulse-height distribution of the recoil deuterons in a proportional counter filled with deuterium. Deuteron recoils produced by neutrons scattered at angles less than 70° in the center-of-mass system were not counted. At 220 kev the scattering was essentially isotropic, but at higher energies backscattering became increasingly important. At 2.5 Mev the differential cross section for 180° was about $2\frac{1}{2}$ times the value for 100°, in agreement with measurements of Coon and Barshall.

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

YA11. Neutron Diffraction Studies of the Lighter Rare Earth Oxides. W. C. Koehler and E. O. Wollan, *Oak Ridge National Laboratory*.—Diffraction studies have been made of the trivalent oxides of lanthanum, praseodymium, and neodymium and also of the divalent oxides of cerium. This work was initiated with the idea of (a) obtaining data on the scattering properties of nuclides in this mass number region, and (b) investigating the magnetic scattering properties of ions of the 4 f series. So far only the nuclear cross section studies have been completed and as a necessary part of this work the crystal structure (for which there has been some disagreement) of the La_2O_3 type compounds used in these measurements has been investigated. In addition to the cross-section studies of the normal elements, values for specific nuclides have also been obtained with isotopically enriched samples. Coherent cross sections were obtained from the powder diffraction patterns and total scattering cross sections from transmission measurements with absorption corrections based on pile oscillator data of H. Pomerance. The following values were obtained for the coherent cross sections in barns: La^{139}(8.7), Ce(2.7), Ce^{140}(2.8), Ce^{142}(2.6), Nd(6.5), Nd^{142}(7.5), Nd^{144}(1.0), Nd^{146}(9.5), and Pr^{141}(2.4).

YA12. The Measurement of Neutron Scattering Cross Sections in the Resonance Region.* C. Sheer, J. Moore, W. W. Havens, Jr., and L. J. Rainwater, *Columbia University.*—An extension of the method[1] for measuring the ratio of scattering to total cross section for slow neutrons in the resonance region (1–100 ev) has been developed, which consists of measuring the ratio of scttered counts from an infinitely thick target of the material under investigation to that of a carbon reference target. The ratio of scattering to total cross section is then obtained by comparing this measured count ratio to that from a similar standard target of known cross section. It has been shown[1] that the calibration curve so derived is valid only when the ratio σ_s/σ_t is <0.5. For values of $\sigma_s/\sigma_t>0.5$ the targets cannot satisfy the criterion of infinite thickness within the geometrical limits of the apparatus. The criterion required when noninfinitely thick targets are used is that both the standard and the unknown have the same thickness in units of the mean free path for neutron interaction. Accordingly, a family of calibration curves are required in which the measured count ratios from a number of standard targets are plotted against relative thickness for various values of σ_s/σ_t. The range of σ_s/σ_t has been extended from 0.5 to 1.0, thus completely supplementing the thick target method. This allows measurements to be made on weak levels and on scattering resonances. The method is illustrated by measurements on the 5.2-ev and 16-ev levels of silver.

* This work was supported in part by the AEC.
[1] Gold, Tittman, and Sheer, Phys. Rev. **83**, 746 (1951).

YA13. Energy Distribution of Slow Neutrons Scattered from Solids. B. N. Brockhouse and D. G. Hurst, *Chalk River Laboratory.*—Neutrons of 0.35-ev energy were scattered at 90° into an annular bank of BF_3 counters by thin specimens of lead, aluminum, diamond, and graphite. The transmission of the scattered neutrons by cylindrical cadmium filters was measured as a function of cadmium thickness. This function is a transform of the energy distribution and could in principle be inverted, provided the energy distribution lies entirely in a region where the cadmium cross section has a steep slope of uniform sign. In practice, however, the measurements were compared with cadmium transmissions calculated for an Einstein crystal model on the Born approximation.[1] Small corrections for multiple scattering were applied. In all cases qualitative agreement was obtained, small divergences being in directions expected from the inadequacy of the model. No significant difference was observed between graphite and diamond. For lead and aluminum at room temperature the simpler model of a gas of free atoms is found to give approximately the same result, as well-known behavior at high energies but here applying when the temperature and neutron energy are only moderttely greater than the Einstein temperature and much less than the binding energy.

[1] We are indebted to Dr. N. K. Pope for the average over initial states.

YA14. Energy Spectrum of Neutrons from the Interaction of 14-Mev Neutrons with C, Al, Fe, Cu, Zn, Ag, Cd, Sn, Au, Pb, and Bi.* E. R. Graves and L. Rosen, *Los Alamos Scientific Laboratory.*—Thin-walled spherical shells of the above listed elements were placed around a nearly monoenergetic source of 14-Mev neutrons from the $T(d, n)He^4$ reaction. Nuclear emulsions were utilized to measure the spectra of the emergent neutrons. At least 1000 tracks were measured for each element investigated. The distribution in energy of the degraded neutrons for all elements except *C* is rather well represented by Weisskopf's[1] formula $N(E)dE=CEe^{-E/\epsilon}dE$, where $N(E)dE$ represents the number of neutrons having energy between E and $E+dE$. The maxima in the intensities of the degraded neutron spectra occur below 1.5 Mev. This appears to be in contradiction to the predictions of Weisskopf, as does also the observed variation of ϵ with mass number. Our values of ϵ for Bi and Pb are in fair agreement with those previously obtained from this type of experiment.[2,3]

* Work performed under the auspices of the AEC.
[1] V. F. Weisskopf, Phys. Rev. **52**, 295 (1937).
[2] P. H. Stelson and C. Goodman, Phys. Rev. **82**, 69 (1951).
[3] B. G. Whitmore and G. E. Dennis, Phys. Rev. **84**, 296 (1951).

Saturday Afternoon at 2:00

Wardman Park, Continental Room,

(W. F. G. Swann presiding)

Cosmic Rays

Z1. Mean Life of Neutral Penetrating Ray. Rogers D. Rusk and Mildred D. Moore, *Mount Holyoke College.*—A value for the mean life of a neutral penetrating ray has been obtained using a coincidence-anticoincidence counter. The tubes and lead or iron absorbers were kept in fixed positions, while a slab of paraffin below the anticoincidence tube was moved to different positions. A small but definite effect previously reported* and presumed to be due to neutral particles was found to vary with the distance of the paraffin below the anticoincidence tube, dropping to a low value at 70 cm. The curve indicated an observed mean life of the order of 1 to 2×10^{-9} second.

* R. D. Rusk and A. Rosenbaum, Phys. Rev. **76**, 1166 (1949).

Z2. Proportional Counter Measurement of Primary Protons and Alpha Particles. L. R. Davis, H. M. Caulk, C. Y. Johnson, G. J. Perlow, and C. A. Schroeder, *Naval Research Laboratory.*—A balloon flight to 9 g/cm² at Minneapolis ($\lambda=55°$) determined the intensities of primary protons and α-particles. A telescope of thin-walled Geiger counters defined a beam through two proportional counters. The smaller of the two recorded ionization pulses for each event yielded a number-ionization histogram resolving the protons and alphas reasonably well. The alphas were determined both by subtracting a histogram of ground data and by subtracting one made during ascent below 40,000 ft. The mean ratio $R\equiv$(protons/alphas)$=5.7\pm0.6$, the uncertainty being due to the alternative subtraction processes. The intensities at 9 g/cm² atmospheric depth are $I_p=0.24\pm0.01$, $I_\alpha=0.043\pm0.004$ (cm² sec sterad)$^{-1}$.

Z3. Temporal Changes of Nucleonic Component Intensity.* J. A. SIMPSON, W. FONGER, AND L. WILCOX, *University of Chicago.*—Measurements of the nucleonic component intensity as a function of time have been continued using pile structures of lead and paraffin to obtain the local production rates of fast neutrons. The piles are located at selected latitudes at mountain altitudes and sea level. The world-wide intensity variations of ~5 percent which occur frequently (~2 to 4 per month) and persist for the order of days continue to be observed in agreement with our earlier, reported observations. The measurements have now been extended to higher altitudes. Employing an aircraft carrying a fast neutron detector at 30,000-ft pressure altitude, 36 observations of fast neutron intensity were obtained over a 4-month period and compared with the simultaneous recordings of the local neutron production from the pile structures. These measurements confirm the magnitude of the observed temporal changes and show from both the altitude and latitude dependence of the intensity variations that the primary radiation producing these variations generally has energies up to at least 6–8 Bev.

* Assisted by the Flight Research Laboratory, U. S. Air Force.

Z4. The Effect of Equatorial Ring Currents on Cosmic Radiation.* S. B. TREIMAN, *University of Chicago.*—Chapman[1] has suggested that the main phase of magnetic storms and the decreases in cosmic-ray intensity which occasionally accompany these storms[2,3] may both be explained on the basis of a ring current flowing westward in the equatorial plane and having a radius several times that of the earth. The changes in cosmic-ray intensity that would be expected to accompany variations in such a ring current have been calculated, using the simple Stoermer approximation to the theory of allowed cones. For mathematical convenience, the ring current is replaced by the current distribution discussed by Chapman.[1] With these approximations, a simple analytic expression is obtained which relates the changes in the horizontal component of magnetic field at the equator with the corresponding response of an arbitrary cosmic-ray detector located at any latitude and altitude. The theory predicts an increase in cosmic-ray intensity accompanying an increase in the ring current intensity (decrease in magnetic field). During large magnetic storms this increase should be observable at the intermediate latitudes (20°–40°), unless the radius of the ring is quite small.

* Assisted in part by the Flight Research Laboratory, USAF.
[1] S. Chapman, Nature (London) **140**, 423 (1937).
[2] S. E. Forbush, Phys. Rev. **51**, 1108 (1937); Terr. Mag. **43**, 207 (1938).
[3] V. F. Hess and A. Demmelmair, Nature (London) **140**, 316 (1937).

Z5. On the Enhanced Primary Cosmic-Ray Intensity Associated with Solar Disturbances.* M. A. POMERANTZ AND G. W. MCCLURE, *Bartol Research Foundation.*—In an attempt to detect correlations between the primary cosmic-ray intensity and solar phenomena, a series of balloon flights has been conducted during periods when active regions were observed on the sun. The instruments were released in accordance with warnings relayed by either the CRPL at the Bureau of Standards or the Cornell Radio Astronomy Observatory in a cooperative program.[1] The results have indicated that, in addition to a general enhancement of the primary flux which may persist for protracted periods,[2] bursts of intensity sometimes appear to be correlated (despite the rather large statistical uncertainties in the cosmic-ray measurements) with the characteristics of the 200-mc radiation. Such an effect has occurred, for example, in data obtained during several central meridian passages of a particularly active region which has persisted for more than a year, designated 51A by the High Altitude Observatory.[3]

* Assisted by the joint program of the ONR and AEC.
[1] We are indebted to Dr. A. H. Shapley of the Central Radio Propagation Laboratory, and to Dr. C. R. Burrows of Cornell University for providing both data and the warning services.
[2] M. A. Pomerantz, Phys. Rev. **81**, 731 (1951); J. A. Simpson, Phys. Rev. **83**, 1175 (1951); see also Simpson, Fonger, and Wilcox, Phys. Rev. **85**, 366 (1952).
[3] We are grateful to Dr. W. O. Roberts for supplying excellent summaries of solar activity.

Z6. Correlation of Cosmic-Ray Intensities at High Altitudes with Neutron Intensities.* H. V. NEHER, *California Institute of Technology.*—It has been reported by J. A. Simpson *et al.*[1] that a correlation exists between solar activity with its accompanying radio noise and neutron activity as measured at mountain elevations as well as at sea level. In the summer of 1951 a series of balloon flights was made with ionization chambers at Bismarck, during the period when the above neutron measurements were being made. There is a very strong correlation between the fluctuations in the ionization at a given pressure at very high altitudes with the fluctuations in the neutron intensity. At 70,000 ft the ratio between the fluctuations in ionization at Bismarck to the fluctuations in neutron intensity at Climax is 1.7.

* Assisted in part by the joint program of the ONR and AEC.
[1] Simpson, Fonger, and Wilcox, Phys. Rev. **85**, 366 (1952).

Z7. Further Results on the Cosmic-Ray Latitude Effect between Bismarck and Thule, Greenland.* V. Z. PETERSON, H. V. NEHER, AND E. A. STERN, *California Institute of Technology.*—In analyzing the coincident flights between $\lambda m=56°$ N and 88° N the simultaneous fluctuations at the two locations have been removed by relating all flights to one particular day. If the area under the ionization-depth curve is then taken as a measure of the true geomagnetic latitude effect, the balloon data show an increase of less than 1 percent in new energy brought in by primaries in going from $\lambda m=56°$ N to 88° geomagnetic north. There appears to be no new energy beyond 58° to 60° North. While there is an increase in ionization with latitude at a given pressure at very high altitudes, a decrease in ionization with increasing latitude is observed at intermediate altitudes. Some of this behavior can be accounted for qualitatively by a difference in the temperature distribution in the atmosphere at the two locations. The present results agree very well with those obtained up to $\lambda m=64°$ N while flying in B-29's at 30,000 feet.

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

Z8. A Multiple-Wire Ionization Chamber for the Study of Large Air Showers.* R. E. HEINEMAN, *University of Michigan* (*Introduced by* W. E. HANZEN).—A large ionization chamber (8 ft long×2 ft wide×8 in. high) to be used to study the lateral distribution of ionization in large air showers has been equipped with 20 central wires, perpendicular to the length of the chamber. Their spacing can be readily changed to either 2- or 4-in. intervals. Pulses from the wires are amplified and their display on a 20-channel synchroscope is photographed. The aim is to determine the lateral structure function in the region from the core to about $1\frac{1}{2}$ meters from the core, within which region two $1/r$ singularities separated by 25 to 50 cm should be resolved. The recording equipment is triggered by a fourfold coincidence of G.M.-counters placed at the sides of the chamber, obviating the difficulties associated with ion chamber triggering. The 4 atmos of argon used to fill the chamber can be purified continuously by circulating it, with an internally located blower, through hot calcium turnings, thereby making negligible the effects of electron attachment to O_2 or H_2O impurities.

* Supported in part by the ONR and AEC.

Z9. Čerenkov Radiation from Cosmic-Ray Particles.* JOHN WINCKLER, *University of Minnesota*.—Although the energy loss of a fast particle ($\beta \approx 1$) due to Čerenkov radiation is small compared to the ionization loss, nevertheless several hundred quanta/cm are released in Lucite, producing photomultiplier output pulses in the range of tenths of volts. In a preliminary apparatus a Lucite radiator 15 cm in length was used in coincidence with Geiger tubes. Internal reflection concentrated the radiation on a phototube in optical contact with one end of the block. This apparatus can be used to separate protons from mesons and electrons, and to study cosmic-ray albedo effects. Data has been obtained at sea level and high altitude and will be discussed. The experiments are being continued with a large radiator 8 in.×8 in.×3 in. thick, to provide greater statistical accuracy for high altitude experiments. The light radiated is proportional to $Z^2(1-1/\beta^2n^2)$, where Z is the number of unit charges, n the refractive index of the radiator, and $\beta = v/c$. A contribution to the observed light is made by collision electrons produced above the Čerenkov threshold. The light collection problem is more difficult than in scintillation counters due to the sharp angular dependence of the Čerenkov radiation.

* Research supported by the joint program of the AEC and ONR.

Z10. The Collision Cross Section of High Energy Primary Cosmic Rays. HAROLD K. TICHO, *University of California, Los Angeles*.—Altitude curves of penetrating showers produced in a lead block have been re-analyzed. Showers of all sizes exhibit an attenuation length of $\sim$125 g/cm^{-2} in air. By extrapolation to the top of the atmosphere and comparison with the energy spectrum of primaries, an energy of >260 Bev has been assigned to the particles causing the largest showers if the primary spectrum varies as $E^{-1.8}$; if the spectrum in the 100–1000 Bev region is flatter, then the energies of the particles causing the largest penetrating showers should be still larger. It is generally believed, that the attenuation length is twice as long as the geometric collision mean free path because of contributions to the counting rate from secondaries originating in interactions at higher altitudes. Such secondaries could be nucleons and pions; if they are nucleons, then the collisions would have to be much more elastic than present nuclear emulsion results suggest; if they are pions, then a calculation of the corresponding underground μ-meson intensity yields a result which is larger than the measured μ-meson intensity by a factor >10. As a result it appears that neither recoil nucleons nor pions can explain the difference between the observed attenuation lengths and a geometric collision mean free path.

Z11. A Coincidence Method for the Investigation of Cosmic Rays Using Scintillations in Liquids. J. HERSHKOWITZ, H. P. KALLMANN, AND W. A. SCHNEIDER, *New York University*.*—A triple coincidence telescope has been developed which uses two scintillation liquid columns and a monitoring crystal to provide data on the energy of individual cosmic ray particles. Photomultipliers with associated amplifiers are used to produce a single trace on a scope screen for each triple coincidence. The screen is continuously photographed and the beam is unblanked and intensified by the pulse from the monitoring crystal. The coincidence arrangement eliminates spurious effects produced by background noise and low energy particles through the liquids and crystal. Under the assumption that the length of the trace is proportional to the energy absorbed by the liquid, one finds a sharp peak in the number *vs* energy curve. The ratio of the energy difference between the half-value points to that of the most frequent energy ($\Delta E/E$) in 0.36. The number of triple coincidences was measured as a function of geometry and found in all cases to be in agreement with known values of cosmic ray intensity at sea level. Further studies are underway on the energy distribution of cosmic rays and their absorption in various liquids.

* This work was assisted by Signal Corps.

Z12. Electric and Nonelectric Scattering of Cosmic-Ray Mesons and Protons.* W. L. WHITTEMORE AND R. P. SHUTT, *Brookhaven National Laboratory*.—An experiment has been performed at sea level and at 3.4-km altitude to study the scattering in 5 cm of lead of 15,000 cosmic-ray mesons and protons whose momenta were measured before entering the lead plate. Since the particles at sea level are mostly μ-mesons, the scattering is mainly electrical and agrees within statistics with the theories of Molière, Scott and Snyder, and Olbert. At 3.4-km altitude the distribution in scattering angle for negative particles also agrees within statistics with the Coulomb-scattering theories, whereas the distribution for positive particles definitely possesses a "tail" which is not in agreement. However, the angular distribution in this "tail" alone exhibits a strong preference for forward scattering, indicating (elastic) diffraction scattering on the lead nuclei of the fairly intense proton components[1] at high altitude. The number of observed cases of scattering through very large angles, some of which might also be elastic, can be combined with the number of anomalous stopping and star production events to give the proton reaction cross section of lead nuclei.

* Work done at Brookhaven National Laboratory under the auspices of the AEC.
[1] W. L. Whittemore and R. P. Shutt, Bull. Am. Phys. Soc. **27**, No. 1, 17 (1952).

Z13. The Variation of the Positive-Negative Ratio of Cosmic-Ray Mesons with Momentum and Altitude.* H. A. MOREWITZ AND M. H. SHAMOS, *New York University*.—We have used the method of delayed coincidences to measure the integral and differential time distribution of decay electrons from μ-mesons which were stopped alternately in a carbon and in a sulfur absorber under $\sim$11 cm of lead. The experiment has been operated for $\sim$4000 hours, of which $\sim$825 hours were background (no absorber). The data for decay times >2 μsec was analyzed by the statistical method of Peierls and yields 2.09±0.05 μsec for the mean lifetime of the μ^+-meson in sulfur. This is in agreement with the value found by Alvarez *et al.* in stilbene, but does not agree too well with a recent value reported by Bell and Hinks in iron. The difference between the carbon and sulfur delayed coincidence rates gives 1.92±0.04 μsec as the mean lifetime of the μ^- meson in carbon, in accord with Wheeler's theory of μ^- meson capture. The integral time distributions were extrapolated to zero time and allowance was made for those μ^- mesons which were captured in carbon. From this information the μ^+/μ^- ratio for a momentum of $\sim$250 Bev/c at sea level was computed to be 1.06±0.03. The μ^+/μ^- ratio was plotted as a function of momentum from the top of the atmosphere.

* This work was supported by the ONR and AEC.

Z14. Absorption of Cosmic Rays under 120 MWE of Earth.* C. A. RANDALL, *Ohio University*.—Absorption in lead and in carbon for twofold and threefold coincidences between trays of G-M counters are being obtained, in a coal mine under 120 mwe of earth. The apparatus is similar to that used at 850-mwe depth.[1] The absorption data will be shown and preliminary interpretation discussed. The results appear to be consistent with the hypothesis that the component which is almost completely absorbed by approximately 10 g/cm^2 of lead consists almost entirely of knock-on electrons from μ-mesons.

* Supported in part by the ONR and Ohio University Fund.
[1] C. A. Randall and W. E. Hazen, Phys. Rev. **81**, 144 (1951).

SUPPLEMENTARY PROGRAMME

SP1. Equilibria in Liquid Systems. GEORGE ANTONOFF.*—Two substances showing a marked deviation from Raoult's law have a tendency to separate into two layers, owing to interaction in accordance with Mendeleiev's theory. On addition of B to A the complex Z is formed and the number of molecules in solution remains constant. Z follows in accordance with Van't Hoff's simple gas laws. It associates with itself in stages of $Z+Z=Z_2$; ${}^2Z_2=Z_4$, etc. The heavy molecules form a sediment of two layers, containing the same number of molecules per unit volume, i.e., $N_1=N_2$; $N=d_1/M_1=d_2/M_2=d_2/M_1X$, where N is the number of mols per unit volume, d=density, M=molecular weight, and X=association factor. With changing t association takes place in stages. Thus properties show kinks which are seen best if $d_2=d_1$ is plotted *vs* t. Best example is phenol-water with critical t at 70°C. Within the solvent Z behaves as a typical gas.

* To be given at the end of Session C if the Chairman rules that time permits.

SP2. The Nature of Nuclei and Elementary Particles. ENOS E. WITMER, *University of Pennsylvania.*—In abstract No. Y11 the writer reached the conclusion that *m, the rest mass of the negative electron, is the natural unit of mass for nuclei and elementary particles.* We believe that the results stated therein cannot be explained by any theory in which the nucleus is regarded as composed of elementary particles that have a potential energy which is a continuously varying function of the space coordinates of the elementary particles. It seems likely that it will be necessary to give up the concept of elementary particles except as an approximation in certain limiting cases. The fundamental new fact in the nuclear domain is the creation and destruction of material particles. The occurrence of transitions between states with different particles present means that in a complete theory the *whole set of such transitions must be considered simultaneously.* Consequently, the masses of all nuclear and cosmic-ray particles will be obtained in one operation in terms of a universal mass constant *m.* Thus, the unity in such a scheme is inherent in the *theory,* not in the existence of elementary particles regarded as the building blocks for the other particles.

* To be given at the end of Session Y if the Chairman rules that time permits.