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Ernest O. Lawrence Radiation Laboratory

PHYSICS DIVISION SEMIANNUAL REPORT
May through October 1958

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Berkeley, California

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GENERAL PHYSICS RESEARCH

PHYSICS RESEARCH

Luis W. Alvarez in charge

LIQUID HYDROGEN BUBBLE CHAMBERS

Operation and Development

James Donald Gow

4-Inch Chamber

The 4-inch chamber has been in use at the 300-Mev electron synchrotron during the past six months. An integrated total operating time of about $2\frac{1}{2}$ months has accumulated. All the operating during this report period has been with liquid deuterium. The operation has been carried out principally by personnel of the synchrotron group, with only minimal supervision and assistance from the bubble chamber group.

15-Inch Chamber

During the first two weeks of May, the chamber continued to operate on the K^--capture experiment. During a Bevatron shutdown in the latter half of May, the chamber was removed from the magnet to permit precision measurement of the magnetic field. On June 4 a run with deuterium, using a supply having a low tritium analysis, was begun. This run was successful in every respect, and continued through June 24. For normal sensitivity, a deuterium vapor pressure of 100 to 105 psig was found optimum. Upon the accumulation of a sufficient number of K^--d interactions, operation was switched back to hydrogen.

The K^--capture experiment was interruped on July 1 to permit the installation of a thin movable plate which covered the expansion openings. This plate was installed in the hope of eliminating eddies of hydrogen having a different temperature from that of the bulk of the chamber liquid. These eddies produced small random optical displacements of the tracks due to differences in index of refraction. The K^--capture run was resumed on July 22, using the movable-plate expansion system, and continued, using both deuterium and hydrogen, until August 9.

The movable plate proved incapable of eliminating the optical turbulence, apparently owing to the leakage of liquid hydrogen around the edges.

During this run, careful observation indicated that the optical distortions were caused by warm hydrogen being forcibly injected into the chamber volume during recompression. In order to obviate this effect, the opening through which expansion takes place was moved to the side of the chamber away from the expansion line. An inner liner of copper was provided, which formed an annular duct connecting the expansion line with the relocated expansion plate. This system provides a large amount of heat-exchange surface along the path from expansion line to the holey plate, and assures that liquid entering the chamber on recompression is in thermal equilibrium with the bulk of the chamber liquid.

A short test run was made which confirmed the expectation that this duct system would eliminate the short-wave-length optical turbulence. The chamber was then dismantled to permit installation of a better duct system and made ready for the next run. This run is scheduled to begin early in November, and will utilize a beam of 1.2-Bev/c K^- mesons, electromagnetically separated, to further study the interactions of K^- mesons with protons.

72-Inch Chamber

Early in May, the 72-inch magnet was moved from its outdoor assembly pad into Building 59 by use of the hydraulic "walking" system. This method of locomotion proved satisfactory and the chamber was placed in the position desired for the first test runs.

The installation of the refrigeration equipment and the compressor-room equipment proceeded through the summer months. The initial assembly of the internal chamber components also proceeded, although there was some delay owing to extraordinarily heavy mechanical shop loads.

By mid-August preparation for the first test run of the complete system started, and a test run, using nitrogen as a working fluid, was begun on September 3. This test was designed to simulate hydrogen operation in every important respect. The cool-down was accomplished by using nitrogen in the refrigeration system and nitrogen was condensed to fill the chamber. The expansion and recompression system operated as designed and no major difficulties were encountered during the test. The compressor system gave some trouble and a few very minor difficulties turned up in cold-valve designs and in some instrumentation.

Several minor leaks from internal plumbing in the main vacuum system occurred, but none were severe enough to interfere with the test run. The inflatable window gasket sealed at 400 psi internal pressure. Successful superheating was accomplished, and radiation-induced boiling was observed in the liquid nitrogen.

The test run occupied 30 calendar days from the start of cool-down to the removal of the chamber assembly from the vacuum system at the end

of the test. Analysis of the test data has shown that we can proceed to hydrogen operation with a high degree of confidence. During October the major effort was on the fabrication of the optical system and on the completion of the hydrogen safety system. Reworking of instrumentation and the compressor system proceeded. During November and early December, the chamber will be made ready for the first operation with liquid hydrogen.

A 22-foot-diameter spherical tank was installed during the summer months. This sphere will serve as a receiver in the event of emergency venting of hydrogen or deuterium, replacing the burning system used with the 10- and 15-inch installations. The sphere will normally be under vacuum, and has been tested for both pressure and vacuum conditions. In the vacuum test, the sphere was pumped to a pressure of 7 microns by using a KC 15 mechanical pump.

The operating staff was brought together during the summer and fall, and a training program, designed to acquaint the group with both theory and practice, is being conducted. On October 31, all the elements of the system envisioned nearly four years ago are in hand, have been individually tested, and have operated together using nitrogen as a dummy working fluid. The final phase of the construction period, a full-scale test with hydrogen, should be completed in the next three months.

Optics and Data Reduction

Hugh Bradner

Activity has continued as described in the preceding semiannual report.

Results of Experiments Performed with Hydrogen Chambers

Associated Production of Strange Particles

Analysis continued on the data obtained in the 10-inch liquid hydrogen chamber run which terminated December 1957. Information not contained in the preceding semiannual report follows. The world's first example of a Λ undergoing beta decay was found (Phys. Rev. Letter, in press). A null result was obtained in a search for parity nonconservation in the (strong interaction) associated production process (Phys. Rev. Letters 1, 209 (1958)). Decay branching ratios were obtained,

$$P_\Lambda = (\pi^- + p)/\text{total} = 0.59 \pm 0.04,$$

$$P_K = (\pi^- + \pi^+)/\text{total} = 0.36 \pm 0.03.$$

These agree well with the "$\Delta I = 1/2$ Rule," in contrast to previously published results from other laboratories. Lifetimes were obtained,

$$\tau_\Lambda = 2.79 \pm 0.22 \text{ (based on 636 events)},$$

$$\tau_{K^0} = 0.99 \pm 0.06 \text{ (based on 399 events)}.$$

Alvarez

A new and improved Σ^0 mass value was obtained, based on a single event in which the Σ^0 underwent the extremely rare mode of decay $\Sigma^0 \rightarrow \Lambda^0 + e^- + e^+$ (Phys. Rev. 111, 1707 (1958)). Two events were found which beautifully demonstrate the predictions of Gell-Mann and Pais with regard to the change of strangeness of K^0 mesons with time. The events show the sequence $\pi^- + p \rightarrow \Lambda^0 + K^0$,

$$\Lambda^0 \rightarrow p + \pi^-, \quad K^0 \rightarrow 50\% \bar{K}^0 + 50\% K^0,$$

(not observed directly. Given by G.-M. and P. theory),

$$\bar{K}^0 + p \rightarrow \Sigma^+ + \pi^0, \quad \Sigma^+ \rightarrow n + \pi^+.$$

The observed particles, Λ^0 and Σ^+, both have strangeness -1, so that one has "apparent" nonconservation of strangeness.[1] A detailed analysis of the production and decay angular distribution of $\pi^- + p \rightarrow \Lambda^0 + K^0$ at 1.12 Bev/c showed that S wave, P wave with spin flip, and P wave without spin flip are all about equally important in the final state, and there is no evidence for any D wave.[2] By use of the Lee-Yang method, and on the basis of 437 Λ decays, the spin of the Λ has definitely been established as 1/2, independent of any assumptions except angular-momentum conservation. At the time of the 1958 CERN Conference, our then total of 236 events gave only 1.43 standard deviations against spin 3/2. Including the rest of the world's supply--162 events--raised the odds only to 2.26 standard deviations. We now have 185 additional events and can on the basis of our data alone rule out spin 3/2 by 3.2 standard deviations. Including the rest of the world's events raises this to 3.5 standard deviations.

K^--Meson Absorption in Deuterium

After deuterium had been obtained sufficiently free of tritium, a successful exposure to the 180-Mev/c K^- beam was carried out. The film has now been scanned, and 3/4 of the useful events have been measured and analyzed. A tabulation shows that 3500 K^- mesons entered the chamber, and 2300 underwent interactions leading to hyperon production. The remainder decayed in flight or had sufficient momentum to leave the chamber. Though a large variety of reactions occurs in deuterium, most event types are easily recognized. Many of the ambiguous events can be properly identified when measurements are completed. It will then be possible to make a test of charge independence in strange-particle reactions with good statistical accuracy. Results up to now indicate that there are no strong disagreements with the predictions of the charge-independence hypothesis.

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[1] Crawford, Cresti, Good, Gottstein, Lyman, Solmitz, Stevenson, and Ticho, Evidence for the Transition of a K^0 into a $\bar{K}^0$ Meson. Phys. Rev. (in press).

[2] 1958 High-Energy Physics Conference, CERN Report, and to be published.

A particularly interesting effect was observed in examining the K^--d events leading to the formation of $\Lambda\pi^-p$. The momentum spectrum of the π^- mesons accompanying the reaction shows a very marked two-peak structure. It is felt that the high-energy peak arises from the direct production of Λ's in the primary absorption process, while the low-energy peak results from the production of Σ hyperons, which convert internally to Λ's in secondary interactions with the spectator nucleon. A detailed kinematic analysis of the events is in progress and is discussed elsewhere in this report (see section by Dr. Edward Lofgren's group).

Interactions of K^- with Hydrogen

During May, June, July, and the first 10 days of August, the 15-inch run in the electrostatically separated K^--meson beam was completed. For a few days of this time K^- mesons were stopped in deuterium (the results are described separately), but during most of the time K^- of 180, 300, and 400 Mev/c were passed into hydrogen. All together 350 rolls of film (each with 360 exposures) were obtained. These contain a total of ~7000 K^- stoppings (yielding hyperons) and ~1000 K^- interactions in flight.

Before analyzing this large group of data it is necessary to measure them (our "Franckenstein" can measure about 50 events per day) and run them through IBM programs. The processing was split into two groups. For the Annual International Conference on High-Energy Physics at CERN one-fourth of the interactions in flight were processed, by using IBM 650 programs and hand fitting. These data were reported at CERN, along with a phenomenological analysis by R. Dalitz. It has been decided to run the rest of the events through new IBM 704 programs (PANG and KICK), which were being written during the summer. It will take at least another half year to work through the remaining events.

One important event was found; a beta decay of the lambda hyperon. A similar event was found a few days earlier among the associated-production events already gathered by this group. They are the only unambiguously identified events of this class found so far.

PHYSICS RESEARCH

Walter H. Barkas in charge

HYPERON AND K^--MESON RESEARCH

Walter H. Barkas, Nripa N. Biswas, John N. Dyer, Harry H. Heckman, Conrad Mason, Norris Nickols and Frances M. Smith

Decay of K^- Mesons

Approximately 70 decaylike events have been found in the 1U and 2B stacks. Of those so far analyzed, 11 have proven to be K^- interactions in flight, 16 are decays into muons, 13 into pions, and 2 into electrons. To date, the τ decay mode has not been seen by us, although in other studies it has been observed.

To facilitate the identification of secondary tracks a device for semi-automatic readout and tabulation of electron-track ionization data has been built. It is now being used to aid in the estimation of the particle velocity when a track is found to leave the stack, and to determine the masses of particles that stop in the stack.

Asymmetry in Σ^- Hyperon Decay

In an attempt to observe a directional asymmetry in the decay pion, if such exists, we have tabulated data from the observed decay of 128 charged Σ hyperons. The events studied were those in which a K^- meson came to rest and interacted with a bound proton, producing a Σ hyperon that decays, and a pion. Only "clean" interactions--showing no other visible emitted particles--were chosen. The angle studied was that between the normal to the "production" plane (which we defined as $\hat{P}_\Sigma \times \hat{P}_\pi$) and the direction of the decay pion ($P_{\pi'}$) from the sigma decay. In the cases in which the sigma hyperon decayed in flight, the center-of-mass angle was calculated.

Angles less than 90° are "positive" or "up," and those between 90° and 180° are "negative" or "down." The up/down ratios observed were as follows:

Σ^+	$\rightarrow$	π^+ (at rest)	23/15
$\Sigma^\pm$	$\rightarrow$	$\pi^\pm$ (in flight)	15/18
Σ^+	$\rightarrow$	π^0 (at rest)	17/22
Σ^+	$\rightarrow$	π^0 (in flight)	9/ 9

It is possible that when a K^- meson interacts at rest with a complex nucleus the residual polarization of the Σ hyperon is so small that any asymmetry that exists is washed out. Recent counter experiments have given evidence of a strong asymmetry in the neutral-pion mode of Σ^+ decay (Rodney L. Cool; private communication).

Capture Mechanisms of K^- Mesons

Reactions producing charged hyperons are now being studied to gain information on the K^- + (p) interaction itself. The momenta of the Σ hyperon and of the associated pion are being determined. The momentum unbalance in the interactions can then be calculated. Further, the production angle of the Σ hyperon with respect to the direction of motion of the bound proton can be examined for a possible asymmetry which would occur with a significant amount of "p" state.

We will examine also the energy distributions of the pions and Σ hyperons from these events--mostly from light nuclei--and the distributions of pions and Σ hyperons from K^--meson interactions in which three or more charged particles are associated with the event.

Decay Modes of Charged Σ Hyperons

We have continued our analysis of decays of charged hyperons in which the decay product produces a track of near-minimum ionization. Of the 145 events of this type that we have located in our 2B and 2D stacks, we have followed 54 secondary tracks to their termination in emulsion or to their point of exit from the stack. Eighteen secondaries were pions that came to rest in emulsion. The number of interactions in flight agrees with the number expected from strongly interacting secondaries. The events in which the secondary left the stack are all consistent with the pion mode of decay. We have observed no event in which a lepton is emitted at low energy, although in several cases it is possible that a lepton could have been emitted with enough energy to leave the stack and escape detection.

Efforts to determine masses of the secondaries that leave the stack have produced inconclusive results. Analysis of the 145 events above will continue in order to (a) search for leptonic decay of the charged hyperon, and (b) obtain a value for the mass of the neutral pion from the reactions $\Sigma^+ \rightarrow \pi^+ + n$ and $\Sigma^+ \rightarrow \pi^0 + p$.

The K^--Meson and Σ^--Hyperon Masses

Combining data from our 2B, 2D, and 1U stacks, we have reported measurements made on 20 events in which a K^- meson comes to rest in emulsion and produces two collinear tracks. These are assumed to be instances of the reaction $K^- + p \rightarrow \pi^\pm + \Sigma^\mp$ on a free proton. From the measured difference in ranges of the Σ^- and Σ^+ hyperons, their mass difference can be determined. We have previously determined the mass of the Σ^+ from the decay $\Sigma^+ \rightarrow p + \pi^0$, and thus can obtain $M_{\Sigma^-} - M_{\Sigma^+}$ (mass difference). We have reported the following masses:

Σ^-, 1195.8 ± 0.5 Mev,

and

K^-, 493.87 ± 0.46 Mev.

Barkas

Study of Λ Hyperons Produced in K^--Meson Interactions

A study of the Λ-hyperon decay, the primary aim of which is to establish the mass of the Λ^0 and the Q value of the decay via the proton mode, is continuing.

Area scanning to locate Λ-like events in an emulsion stack is in progress, and to date approximately 60% of the total volume has been scanned. These events plus 11 additional events in another emulsion stack yield a total number of 73 Λ-like events observed by the end of October.

Analysis of these events has been started. Range measurements of the decay prongs have been taken and the corresponding ranges computed for 90% of the events. Measurements of the decay angles are now being carried out.

The development of a digitized microscope with automatic coordinate readout was brought to a successful conclusion and the use of this instrument has greatly facilitated making range measurements. We find that events can be measured in a quarter of the time that was necessary prior to the development of this instrument. In addition, since data are recorded directly on IBM data cards, range computations can be performed by using the IBM 650 data processing machine, reducing computation time by a factor of 500.

MINOR DECAY MODES OF K^+ MESONS

Harry H. Heckman and Jack W. Patrick

Preliminary results from the analysis of K^+ decay modes, observed in the 30-inch propane bubble chamber, have been obtained from the 650 machine code and show an encouraging relation to the previously established emulsion information. Approximately 4500 decay events were recorded, of which 1400 were classed as measurable. The momentum resolution of each of the two-body decay modes appears to be 10%. Since the momenta of the $K_{\mu 2}$ and $K_{\pi 2}$ decay modes are separated by only 15%, complete resolution of two decay modes is difficult.

Work is proceeding on the resolution of the remaining modes of decay. Approximately 50 obvious $K_{\beta 3}$ decay events have been found, or 25% of the number expected. This indicates that further analysis of the K_3 events may be necessary to find all the mesons, decaying by the $K_{\beta 3}$ process, that are actually present. A detailed program is now under way to obtain the branching ratios of the minor decay modes, the energy spectra of the β and μ in the $K_{\beta 3}$ and $K_{\mu 3}$ modes, and the distribution of Dalitz pairs.

HEAVY-ION RESEARCH

Harry H. Heckman, Betty L. Perkins, and Walter H. Barkas

Preliminary range-energy curves in emulsion for argon, neon, oxygen, nitrogen, and carbon ions for energies up to 10 Mev per nucleon

have been obtained. Refinements of these measurements are continuing. The measurements have been made by using 180° deflection of the ions in a magnetic spectrometer. The ranges are now known to better than 1%, and they will be improved further.

Experiments are under way in which we observe the distributions of charge states of heavy ions as they emerge from foils of various kinds and with various velocities. Efforts are also being made to improve the theory of stopping of heavy multiply charged ions.

The tracks of ions in emulsions of systematically varying sensitivity and type of development have been studied. Remarkable mechanical effects that alter the geometry of the tracks can be produced by physical development of the tracks of these highly ionizing particles. As the development time increases the tracks begin to buckle, and eventually look like "corkscrews." When the ions are caused to enter the emulsion perpendicular to its surface and the tracks are subsequently strongly developed they become such incompressible rods of silver that after processing they are found to extend above the emulsion surface for several microns--and by an amount that varies with the atomic number of the ion.

PHYSICS RESEARCH

A. C. Helmholz in charge

Reported by Robert W. Kenney

NEUTRON CROSS SECTIONS

The work of the Helmholz group in cooperation with the Moyer group (John Atkinson, Wilmot Hess, Victor Perez-Mendez, and Roger Wallace) on neutron total and absorption cross sections is reported under the Moyer Group's section of this document.

GAS CHERENKOV COUNTERS FOR HIGH-ENERGY PARTICLE DETECTION*

John H. Atkinson and Victor Perez-Mendez

A number of gas-filled Cherenkov counters have been built for use as threshold detectors for particles with β ranging from 0.986 to 0.999. The filling gases used have been CCl_2F_2 and SF_6, both of which have relatively high indices of refraction and are transparent in the visible and ultraviolet. The counter consists of a steel cylinder 6 feet long and 4 inches in diameter, filled with gas. At the rear end a plane front-surface mirror reflects the light at 90 degrees to the incident direction up to the photomultiplier, a 16-stage RCA C 7232A. The performance of the counter was checked in a 3.0 ± 0.1-Bev pion beam to determine the slope of the threshold sensitivity curve so that a counter of this type can be used as a detector for elastic scattering experiments.

POSITIVE-PION PRODUCTION BY π^- AT 260, 317, AND 371 Mev*

John C. Caris, Robert W. Kenney, Edward A. Knapp, Victor Perez-Mendez, and Walton A. Perkins

Positive π mesons from the reaction $\pi^- + p \rightarrow \pi^+ + \pi^- + n$ were detected by using a counter telescope which selects the π^+ by its characteristic π-μ decay. With the 260-Mev π^- beam, π^+ mesons were counted at 90°(lab). At 317 and 371 Mev the differential production cross section was measured for π^+ mesons emitted at 60°, 90°, 125°, and 160° in the barycentric system. The angular distributions are nearly isotropic at both energies. On the assumption of a similar angular distribution at 260 Mev, a preliminary analysis of the data gives total cross sections of 0.20 ± 0.12 mb at 260 Mev; 0.75 ± 0.25 mb at 317 Mev; and 2.0 ± 0.5 mb at 371 Mev.

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*Title and substance of abstract submitted for Los Angeles Meeting of American Physical Society, Dec. 29-31, 1958.

POSITIVE PION SCATTERINGS FROM COMPLEX NUCLEI AT 440 Mev

John Caris, Edward Knapp, Victor Perez-Mendez and Walton Perkins

The total and absorption cross sections for positive pions at 440 Mev incident energy on carbon, aluminum, copper, and cadmium were measured. The data are being analyzed in terms of the optical-model potentials derived by Kenneth M. Watson.

CHARGE-EXCHANGE SCATTERING AT CYCLOTRON ENERGIES

John Caris, Robert W. Kenney, Edward Knapp, Victor Perez-Mendez, and Walton Perkins

Angular distributions for the reaction $\pi^- + p \rightarrow \pi^0 + n$ were measured by counting the π^0-decay gamma rays for incident π^- energies (lab) of 260, 320, and 370 Mev. The inversion of the observed γ-ray angular distribution to a π^0 angular distribution is in progress.

ANGULAR DISTRIBUTIONS OF PHOTOPIONS FROM HYDROGEN

Robert Kenney, Edward Knapp, and Victor Perez-Mendez

Final data on the reaction $\gamma + p \rightarrow \pi^+ + n$ have been taken for photon energies of 260 and 290 Mev and for pion angles from 0° to 160°(c.m.).

The differential cross section was observed to be flat in the angular region between 0° and 40°, owing to photoelectric ejection of pions from the meson cloud. The complete angular distribution is in satisfactory agreement with the dispersion relations of Chew et al.

PHOTOPION PRODUCTION FROM DEUTERIUM

John Anderson, Duane Gates, Thomas Jenkins, Robert Kenney, and William Swanson

The 4-inch liquid hydrogen bubble chamber has been filled with deuterium and placed directly in the synchrotron beam. The reactions $\gamma + d \rightarrow \pi^- + 2p$ and $\gamma + d \rightarrow \pi^+ + 2n$ have been observed (approximately 4000 events), and measurements of angular distributions of the final-state particles are in progress. Comparisons with the recent "Pology" theory of Chew and Low will be made.

Helmholz

THEORETICAL GROUP

David L. Judd

PHYSICS OF THE NUCLEUS

A study was completed of the excited states of nuclear matter.[1] This represents an extension of the work of Brueckner and his collaborators, as applied to nuclear ground states. Beginning with two-particle forces, the following excited modes were found: (a) a simple hydrodynamic or "sound wave" mode; (b) a "Goldhaber-Teller" mode; (c) a spin wave mode; (d) a mode involving coupled spin and I-spin waves. Possible means for the experimental investigation of these were considered. (Warren Heckrotte, Alfred E. Glassgold, and Kenneth M. Watson)

The methods used by Heckrotte, Glassgold, and Watson (see description above) for collective excitations are applied to calculations of the ground-state energy of nuclear matter. This represents a considerable improvement in the approximations used by Brueckner et al. for the same problem. The work is presently in the stage of final numerical calculations. (Yih Pwu)

In connection with studies of nuclear fission based on the liquid-drop model, the deformation energy of slightly distorted spheroids was investigated. By use of an IBM 650 computer in conjunction with formulae obtained with the aid of spheroidal harmonics of orders one through ten, second-order expansions for the surface and electrostatic energies were computed by using prolate spheroids with axes in the ratio 1.4 through 12.6. (Stanley Cohen and W. J. Swiatecki)

Studies of the deformation energy of a charged drop, as reported earlier,[2] were continued. In this connection attempts are being made to study experimentally the disintegration of charged drops of water suspended in an insulating solution of carbon tetrachloride and mineral oil of the same specific gravity. (W. J. Swiatecki)

The analysis of data from time-of-flight measurements of neutrons accompanying the spontaneous fission of Cf^{252} is being carried out jointly with the authors.[3] (W. J. Swiatecki)

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[1] Glassgold, Heckrotte, and Watson, Collective Excitations of Nuclear Matter, Phys. Rev. (to be published).

[2] Wladyslaw J. Swiatecki, Deformation Energy of a Charged Drop (paper given at Second Geneva Conference on Peaceful Uses of Atomic Energy, Sept. 1958.)

[3] H. R. Bowman and Stanley G. Thompson, The Prompt Radiations in the Spontaneous Fission of Californium-252, UCRL-5038, March 1958.

Heavy-ion bombardment of heavy nuclei can lead to the formation of compound nuclei with total angular momenta of 100 to 150 $\hbar$. The large rotational energies associated with these high angular momenta are expected to significantly alter the fission barrier. Equilibrium configurations and saddle-point shapes for such rotating nuclei are being studied. (John R. Hiskes and W. J. Swiatecki)

Stewart Bloom has suggested that a γ-nuclear recoil experiment could be carried out with Be_7, which goes to Li_7 by K capture. I have done the corresponding calculation and find that the experiment should give a sensitive measure of the ratio of Gamow-Teller to Fermi matrix elements. A report is in preparation. (Jack Uretsky)

Work has continued on the use of perturbation theory in the many-fermion problem. In connection with this the predictions of the theory with regard to the scattering of very slow neutrons from liquid He^3 have been studied. (David J. Thouless)

NUCLEON-SCATTERING THEORY

The WKB optical-model wave functions, which describe the scattering of nucleons from both nuclear spin-orbit and central potentials, have been applied to the deuteron pickup process and to the elastic scattering of nucleons by nuclei. The polarizations and cross sections, which can be obtained in closed form, are in excellent agreement with experiment in both cases. The detailed results for the pickup process were the subject of a Ph. D. thesis.[4] A report is being written describing the results obtained by applying this method to the elastic scattering of nucleons by nuclei. Since the calculations required values of spherical Bessel functions for complex argument (not available in the present literature), a preliminary report was prepared giving values of these functions for various complex values of the argument.[5] Also in progress is a similar calculation analyzing the polarization of protons from (p, pn) reactions. (Kenneth Greider)

The conventional optical model does not adequately treat the interaction of a particle with a nucleus in the region of the nuclear surface. Because of the impossibility of localizing the particle orbit in a region of the order of the surface thickness, the concept of a "potential" is inadequate. A modified description is possible, however. (Bernard Lippmann, Charles Zemach, and Kenneth M. Watson)

Stimulated by recent Bevatron experiments with 4.5-Bev neutrons, an investigation of the theoretical interpretation of very high-energy scattering experiments is being carried out. It should be recalled that there are a number of disadvantages in the conventional analysis using phenomenological potentials. For example, there is some question as to the proper form of

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[4] Kenneth R. Greider, The Deuteron Pickup Reaction in an Optical-Model Approximation (Thesis), UCRL-8357, July 1958.

[5] Kenneth R. Greider, Tables of Spherical Bessel Functions for Complex Argument, UCRL-8415, Aug. 1958.

the interaction at very high energies. Then there is always the practical matter of calculating the scattering which, for many partial waves, will involve electronic computers, even if approximation methods are used. We are, instead, proposing to return to the actual phase shifts (which are always defined) and to avoid the conventional Hamiltonian formulation. At the same time, it will be possible to incorporate the semiclassical features of the interaction. A practical method can be formulated if there is considerable absorption of particles in the entrance channel. In particular, it is appropriate to assume that the function $s(\ell) = 1 - |\eta_\ell|^2$ is a continuous function of ℓ which resembles the nuclear density distribution [$\eta_\ell = e^{2i\delta_\ell}$, where δ_ℓ is the complex phase shift for orbital angular momentum ℓ]. This involves the introduction of three parameters: (a) $S_0 = 1 - |\eta_0|^2$, the opacity in the middle of the nucleus, (b) the halfway point L of the distribution $s(\ell)/s_0$, and (c) its surface thickness Δ. In addition, the average value of δ_ℓ should be specified in the transition region. It is then possible to obtain all cross sections in closed form for a variety of assumptions about $s(\ell)$. The method can be generalized to particles with spin and charge. The method proposed here should be regarded as the generalization of the Bethe-Placzek diffraction theory to the case of a diffuse-surface nucleus and scattering amplitudes which are not completely imaginary. Applications to neutron scattering are now being carried out. (Alfred E. Glassgold and Kenneth R. Greider)

The location of the singularities in the nucleon-nucleon scattering amplitude according to local field theory suggests that the analysis of experiments can be much more fruitful if the poles due to exchange of single π mesons are explicitly taken into account. In particular, a determination of the residue of the poles gives the pion-nucleon coupling constant.[6]

A new scheme for analyzing nucleon-nucleon scattering experiments has been developed and applied to p-p scattering data at 310 Mev. The new method is based on an explicit inclusion in all higher angular momentum states of the Born approximation to the one-pion exchange process. This procedure is suggested by Chew's conjecture[6] that the singularities of the scattering amplitude in the $\cos\theta$ plane (θ being the scattering angle in the center-of-mass system) that are closest to the physical region are due to the one-pion exchange process and are given by the Born approximation. Or, alternatively, in terms of ranges, the one-pion exchange contribution has the longest range of the forces contributing to the nucleon-nucleon interaction and hence should be primarily responsible for the contributions to the scattering amplitude in the high-angular-momentum states. Since the only parameter in the Born approximation is the pion-nucleon coupling constant, the new scheme can also provide a determination of this coupling constant. The application of the new method to p-p scattering at 310 Mev indicates that the first two of the five best solutions of the conventional phase-shift analysis are much more satisfactory than the others for two reasons. Firstly, their goodness-of-fit parameters improve markedly when the higher angular momentum contributions are added, whereas those of the others remain essentially unchanged. Secondly, as a function of the coupling constant, the goodness-of-fit parameters of the first two solutions show minima close to the accepted value of the

[6]Geoffrey F. Chew, A Proposal for Determining the Pion-Nucleon Coupling Constant from Nucleon-Nucleon Scattering, Phys. Rev. (to be published).

Judd

coupling constant. Furthermore, solutions No. 3 and No. 4 of the conventional analysis come to coincide with solutions Nos. 1 and 2, respectively, at a certain value of the coupling constant, which indicates that the conventional solutions No. 3 and No. 4 are merely local minima which, when "pushed over" a light barrier, can drop down into the minima corresponding to solutions No. 1 and No. 2. Further work is done to reduce the number of phase shifts used in the analysis.[7] (Henry Stapp and Peter Cziffra, Berkeley; Malcolm MacGregor and Michael Moravcsik, Livermore)

Cziffra (Berkeley) and Moravcsik (Livermore) have analyzed n-p scattering at 90 and 400 Mev on this basis, and together with Stapp (Berkeley) and MacGregor (Livermore) are analyzing p-p scattering at 310 Mev. Eventually all nucleon-nucleon scattering experiments up to 400 Mev will be included. (Peter Cziffra, Michael Moravcsik, Henry Stapp, and Malcolm MacGregor)

ANTINUCLEONS

Measurements of the elastic scattering of antiprotons from complex nuclei have now been carried out in emulsions (Goldhaber et al.), in a propane bubble chamber (Agnew et al.) and with counters (Cork et al.), although with rather poor statistics. The calculations reported previously (Phys. Rev. 110, 220 (1958)) have therefore been extended to the appropriate energies and elements. In the above publication it was shown that the large reaction cross sections arise from strong absorption in the nuclear surface. The elastic scattering is dominated by the related shadow scattering, which makes it difficult to obtain information about the real part of the antiproton-nucleus interaction. Another difficulty is that, at each energy, there are four parameters: V and W (the strengths of the potential) and R and a (the radius and diffuseness of the potential). Although we may assume that the latter do not depend strongly on energy, they may not be the same parameters as in the nucleon density distribution. On the other hand, this may be the simplest assumption to make, which would leave V and W as free parameters. If this assumption is made, the present experiments are consistent with a small real potential, e.g. zero, and an imaginary part based on the classical mean-free-path formula. Real potentials of the order of 100 Mev are ruled out, but it is not possible to be more precise than this at present. This situation could be improved in two ways. First, an improved theory of the imaginary part of the potential is necessary. (For example, the surface is strongly absorbing, so that the assumption of constant nuclear density is surely invalid.) Second, more experiments would permit detailed phenomenological investigations to be made. If the elastic-scattering angular distributions could not be measured at 140 Mev or less, the "total" and reaction cross sections as a function of energy would still be useful. (Alfred E. Glassgold with Sidney Fernbach of Livermore)

[7] Cziffra, MacGregor, Moravcsik, and Stapp, Modified Analysis of Nucleon-Nucleon Scattering. I. Theory and p-p Scattering, Phys. Rev. (to be published).

The theory of Ball and Chew has been extended in energy and in angular distributions by Ball and Fulco.[8] Fulco has used the results to compute the antinucleon mean free path in nuclear matter.[9] The problem of pion production in the annihilation process is being studied by Desai, using the Fermi statistical model but including selection rules. (Geoffrey Chew, James Ball, Jose Fulco, and Bipin Desai)

We have developed a simple model for the treatment of multiple production processes based on the assumption that the matrix element for such a process may be written in terms of the initial- and final-state wave function and some interaction operator, I, as $\int \psi_f^* \, I \, \psi_i \, d\tau_f \, d\tau_i$. We are applying the model to the problem of pion production in antiproton annihilations in hydrogen by correlating it with the calculations by Ball and Chew.[10] (LeRoy F. Cook, Jr. and Joseph V. Lepore)

APPLICATIONS OF DISPERSION RELATIONS TO STRONG-COUPLING PHYSICS

Owing to recent work by Mandelstam it is now possible to write down dispersion relations for individual partial-wave scattering amplitudes. Several applications are being considered: (a) pion-pion scattering (Geoffrey Chew and Stanley Mandelstam), (b) pion-nucleon scattering (Jose Fulco), (c) nucleon-nucleon scattering (David Wong), (d) K-meson–nucleon scattering (Modesto Pusterla). It is hoped that an important extension and codification of strong-coupling physics will result.

A method has been developed for analyzing the scattering of particle A by particle B, leading to three or more final particles, in order to obtain the cross section for the interaction of A with a particle which is virtually contained in B. Binding complications are absent if a plausible assumption about the location and residues of poles in the S-matrix is accepted. The method is useful for unstable particles from which free targets cannot be made.[11] (Geoffrey Chew and Francis Low)

Applications of the method (a) are being made to the determination of the pion electromagnetic form factor from the reaction $e + p \rightarrow \pi^+ + n + e$ (William Frazer), of (b) to the determination of the n-n cross section from $n + d \rightarrow 2n + p$ (Yongduk Kim), of (c) to photopion production from neutrons through $\gamma + d \rightarrow \pi^- + 2p$ (How-sen Wong), and of (d) to the pion-pion cross section through $\pi + p \rightarrow 2\pi + p$ (James Ball).

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[8] James S. Ball and Jose R. Fulco, Nucleon-Antinucleon Scattering; Phys. Rev. (to be published).

[9] Jose R. Fulco, Effective Mean Free Path of Antinucleons in Nuclear Matter, Phys. Rev. (to be published).

[10] G. F. Chew and J. S. Ball, Phys. Rev. 109, 1385 (1958).

[11] Geoffrey F. Chew and F. E. Low, Unstable Particles as Targets in Scattering Experiments, UCRL-8427, Aug. 1958.

The effect of the "one-meson intermediate state" contribution to the effective range formula in nucleon-nucleon scattering is being studied in collaboration with G. F. Chew and H. P. Noyes. (David Wong)

One can make a certain reasonable conjecture concerning the analyticity properties of the amplitude for the photoproduction of pions from nucleons. If the conjecture is valid, the angular distribution contains a pole at the nonphysical point $\cos\theta\ 1/V_\pi$, where V_π is the pion velocity divided by the velocity of light. The residue at this pole (obtained by extrapolation of experimental data) may be shown to be equal to the square of the pion-nucleon coupling constant, apart from known kinemathical factors. The method was applied to available experimental results to yield

$$f^2 = 0.061 \pm .014.$$

The details have been submitted to Physical Review.[12] (Jack L. Uretsky, Michael Moravcsik, and John G. Taylor)

A comparison has been made between the predictions of the dispersion-relation theory and the UCRL experiments on the photoproduction of π^+ mesons from protons. It was concluded that this process does not provide a sensitive test of the dispersion relations because of inadequate experimental knowledge of the "small" scattering phase shifts. The results were published in Phys. Rev. Letters 1, 86 (1958). (Jack L. Uretsky, Robert W. Kenney, Edward Knapp, and Victor Perez-Mendez)

CLASSIFICATION AND INTERACTION SCHEMES FOR ELEMENTARY PARTICLES

A study of the strong interactions between hyperons and nucleons is being undertaken in the hypothesis of a "global symmetry" involving a universal pion-baryon coupling. In particular, the Σ^+-p scattering is investigated on the basis of the Gammel-Thaler potential, which describes satisfactorily the nucleon-nucleon phenomenology below 300 Mev. In contrast with the calculation by Bryan, de Swart, Marshak, and Signell, the Σ^+-p angular distribution is approximately isotropic for the 100- to 150-Mev region. (Fabio Ferrari)

Theoretical interpretation of the empirical evidence on the interactions of K mesons and hyperons with nucleons is reviewed, with the purpose of determining the relative parities of the K particles and the hyperons, and of determining the coupling parameters for the various interactions between them. In particular, the possibility of symmetries between the hyperon-nucleon interactions is discussed, with special reference to the hypothesis of a "global symmetry" involving a universal pion-baryon coupling. The applicability of the dispersion relations for K-nucleon scattering is examined, and it is evident that there are some difficulties connected with the unphysical

[12] Taylor, Moravcsik, and Uretsky, Determination of the Pion-Nucleon Coupling Constant from Photoproduction Angular Distribution, Phys. Rev. (to be published).

region and with the convergence at high energy. Furthermore, some preliminary results on the energy dependence of the K^--p absorption and elastic cross sections are reported. The K^--p data from emulsion studies up to 100 Mev are reproduced by assuming a predominantly S-wave interaction. (Richard Dalitz)

In connection with experiments on the polarization of protons from hyperon decay, formulas have been developed relating the polarization in the laboratory frame to that in the hyperon decay frame. (Sidney A. Bludman and James A. Young)

Various possible nonlocal effects in the electron decay of the pion have been considered. These are no longer of interest, however, since the pion decay rate has been found experimentally in agreement with simple V-A theory. (Sidney A. Bludman and James A. Young)

A description of leptons is discussed in which, neglecting mass differences, $e^-\nu e^+$ is a charge triplet which is, like the π triplet, self-charge-conjugate. This formalism automatically makes the ν a Majorana or two-component spinor. When lepton conservation is assumed, ν must be massless and only V and A forms of e-ν coupling are possible. The possibility is suggested that the μ is a member of a charge doublet along with a neutral particle λ that is different from ν. Since a doublet cannot be its own charge conjugate, μ and λ are not in general massless, even in the non-electric approximation presented here. The charge structure of the leptons $\lambda\mu$ and $e^-\nu e^+$ is then the same as that of the mesons K^0K^+ and $\pi^-\pi^0\pi^+$, but essentially different from that of the baryons n and Σ, for which particle and antiparticle are distinguished by the baryon-conservation law. Whereas the β-decay evidence shows $m_\nu \leq 0.0004\, m_e$, the $\pi \to \mu + \lambda$ and $\mu \to \lambda + e + \nu$ end points allow a much larger value, $m_\lambda \leq 10\, m_e$ for the λ mass. For $m_\lambda \sim 10\, m_e$, the expected ρ value is decreased by ~ 0.03, depending on how ρ is extracted from the experiment. Independently of the λ mass, $\mu \to e + \gamma$ is forbidden absolutely. (Sidney Bludman)

The $\Delta I = 1/2$ rule is incorporated into a previously discussed universal weak Yukawa interaction by assuming the simplest relation between chirality and charge operators. Expressing the $\Delta I = 1/2$ rule by forming N and Ξ into isovectors $\underset{\sim}{B}$ = (p, ip, -n) and (Ξ^-, $i\Xi^-$, $-\Xi^0$) and isoscalars B_S = n and Ξ^0, we assume that $\underset{\sim}{B}$ occurs with $G\gamma_\mu(1 + r\gamma_5)$, as in β decay, and B_S (which has no β-decay counterpart) with $G\gamma_\mu(1 - r\gamma_5)$. Here G is the constant previously fitted to the π and $K\mu_2$ decay rates, and r is the ratio of Gamow-Teller, and Fermi coupling constants. Depending on the sign taken between the $\underset{\sim}{B}$ and B_S interaction terms, Σ decays into $n\pi^+$ in pure S and into $n\pi^-$ in pure P channels, or vice versa. In either case, $\Sigma^+ \to p + \pi^0$ involves maximal S-P interference and $\alpha^0 = 0.98$. Decay into I = 1/2 proceeds via

$$\sqrt{2}\, G\gamma_\mu\left(\frac{1}{2} + \frac{3}{2} r\gamma_5\right) \text{ or } \sqrt{2}\, G\gamma_\mu\left(\frac{3}{2} + \frac{1}{2} r\gamma_5\right)$$

depending on whether Σ^- decay is pure S or pure P. The second case, but not the first, leads to a Λ^0 decay rate in agreement with experiment. In this case we have $\alpha_\Lambda = 0.54$, and in Ξ decay, the decay rate is $1.6 \times 10^{-10}\ \text{sec}^{-1}$ and α_Ξ is 0.64. (Sidney Bludman)

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An attempt has been made to explore the possible connection between symmetry laws in internal space and symmetry laws in Lorentz space with special attention to the question: Why are the strong interactions parity-conserving? For direct pion-nucleon interactions, CP invariance and charge independence are sufficient to guarantee the separate conservation of P and C. For derivative-type pion-nucleon interactions, charge independence and G invariance require that parity (and CP) be conserved; in addition we can also show that the charge-triplet pion must be pseudoscalar, provided the π^0 can be regarded as a bound state of a proton and an antiproton, as far as symmetry laws are concerned. If the K couplings (rather than the π couplings) exhibit a higher internal symmetry in the sense that the K couplings are universal, the high K symmetry plus charge independence in the usual sense imply parity conservation both in the CP-invariant nonderivative-type K interactions and in the G-invariant derivative-type K interactions. The high K symmetry also implies that the relative $N\Xi$ parity as well as the relative $\Lambda\Sigma$ parity is even. It is conjectured that, if the K couplings must be of a derivative type, only ps-pv coupling is allowed, which means that the K particle is pseudoscalar. The global-symmetry model, which cannot be reconciled with our assumption of the high K symmetry, is reexamined. The high K symmetry is destroyed in a specific and definite manner by the π couplings, and relations among the various coupling constants are inferred from the baryon mass spectrum. Whereas G invariance requires the symmetric appearance of the two chiral spinors $\frac{1}{2}(1 + \gamma_5)\psi$ and $\frac{1}{2}(1 - \gamma_5)\psi$ for strangeness-conserving processes, for strangeness-nonconserving processes G conjugation carries charge-conserving interactions into inadmissible interactions that do not conserve electric charge. Hence if we take the point of view that parity-conserving interactions are generated by G conjugation, we have some understanding of the puzzling fact that strangeness conservation and parity conservation have the same domain of validity.[13] (J. J. Sakurai)

FIELD THEORY

The study of spectral representations in perturbation theory was extended to the four-point function (two-particle scattering).[14] (Robert Karplus, Eyvind Wichmann, and Charles Sommerfield)

The integral representation for the field-theoretic vertex operators was written in terms of Lorentz-invariant parameters. Although the conditions are less restrictive than those of Dyson's representation, they do permit treatment of some waves that had to be excluded previously. (Walter Gilbert)

Some further work was done on the implications of conservation laws and their breakdown on the geometry of the Hilbert space. A structure

[13] J. J. Sakurai, Symmetry Laws and Strong Interactions, Phys. Rev. (to be published).

[14] Karplus, Sommerfield, and Wichmann, Spectral Representations in Perturbation Theory. II. Two-Particle Scattering. Phys. Rev. (to be published).

somewhat similar to that familiar in general theory of relativity for configuration space appears. The analog of affine connections for Hilbert-space vectors is the Lagrangian; that of the metric quantities, the representation of charge conjugation and the CPT transformation. (Maurice Neuman)

In connection with studies being made of the mathematical structure of field theories we were led to the consideration of one-nucleon propagators in ps-ps theory. Redmond showed that if field theory is consistent it is possible to obtain a "damped" propagator by summing an infinite set of "elementary diagrams" (details to be published in Phys. Rev.) From this we were led to the conjecture that such damped propagators also exist in nonrenormalizable theories. If the conjecture is correct, the solutions in nonrenormalizable theories are more "convergent" than those in renormalizable theories. For an explanation of these rather confusing remarks see Phys. Rev. Letters 1, 512 (1958). With respect to the ps-ps theory, we have also carried out a calculation of the nucleon magnetic moments with the "damped" propagators. The results are an improvement upon perturbation theory and will be published shortly. (Jack L. Uretsky and Peter J. Redmond)

We have investigated the problem of assigning a measure of the degree of departure from causality of a classical nonlocal field theory from the point of view of dispersion relations. Our procedure has been to write down the dispersion relations satisfied by the Green's function for the particular problem and then to substitute into these relations the nonlocal Green's functions which obviously violate them; the magnitude of this violation is then regarded as a measure of the degree of departure from causality of the theory. (Joseph V. Lepore and Robert Profet)

A nonlocal theory by Pais and Uhlenbeck involving a wave equation with an infinite number of derivatives is being investigated. It has been possible to find a perturbation solution to these equations which is finite in every order, but the evaluation of the integrals is very difficult. The causal properties of the theory are also being studied. (Owen Eldridge)

Dispersion-relation techniques and unitarity conditions are being applied to the study of Compton scattering in quantum electrodynamics with the aim of (a) connecting the infrared divergence with the subtraction procedure, (b) including intermediate states that contain electron-positron pairs, and (c) investigating the possibility of generating the complete perturbation series from the Born terms. (David Wong)

ELECTROMAGNETIC INTERACTIONS

A study of the scattering of charged particles by atoms was completed in the spring of 1958. This work has been extended to include effects due to the Pauli principle, applicable when the scattered particle is an electron. Applications of the method are being made. (Marvin Mittleman of Livermore and Kenneth M. Watson)

Calculations giving the polarization transmitted in electromagnetic cascade showers have been completed. The results are available in the

October 1, 1958 Phys. Rev. Letters. The calculations have been correlated with electron polarizations in μ decay.[15] (LeRoy F. Cook, Jr. and N. A. Williams)

The theory of pair creation by a photon in the field of an orbital electron (triplet production in hydrogen) is being studied. The purpose is to compare the theory with the measurements by Dr. Robert Kenney. (Jack Wong)

PLASMA PROBLEMS

A study of stability of plasma streams is being conducted in cooperation with Lloyd Smith. The Boltzman-equation approach is used, perturbations are assumed small, and all equations are linearized. Both electrons and ions are assumed relativistic. Equilibrium fields are assumed to be zero inside the stream, but perturbation fields, including radial and axial electric along with azimuthal magnetic, are treated as nonzero both inside and outside the plasma. The same problem is being studied from the standpoint of hydrodynamics, again assuming relativistic velocities. In this case the equilibrium azimuth magnetic field is taken into account and the beams are given sufficient angular momentum to create equilibrium. We hope to take into account all components of the fields in this model without making the calculation hopelessly complicated. (Kelvin Neil)

The effect of varying boundary conditions is being studied for several problems of hydromagnetic stability. This includes placing a "mirror" under a plasma supported by a magnetic field (some stabilizing effect is obtained). Also, the role played by a "plasma sheath" is being studied. (Alan Macmahon)

DESIGN STUDIES FOR 88-INCH CYCLOTRON

In order to predict beam dynamics in the magnetic fields measured in the model magnet we have devised a system of using these measurements with certain MURA IBM 704 codes devised by Dr. Francis Cole, known as the ILL-TEMPERED FIVE (ITV). These codes calculate orbits and their relevant properties for particles in fields expressed in the form

$$B(r, o) = B_0(1+x)^k \sum_{m=0}^{m\,max} \sum_{j=0}^{j\,max} (\mu_{mj} x^j \cos m\phi + \nu_{mj} x^j \sin m\phi),$$

where

$$x = (r - r_1)/r_1, \qquad \frac{eB_0}{cP} = \frac{1}{r_1},$$

$$\phi = \kappa n(1+x) - N\theta, \qquad k = \Sigma k_j x^j, \qquad \kappa = \Sigma \kappa_j x^j .$$

[15] Pierre C. Macq, Kenneth M. Crowe, and Roy P. Haddock, Helicity of the Electron and Positron in Muon Decay, UCRL-8263, July 1958.

With the assistance of R. Harvey, a 650 code called SEACY has been prepared which, for any momentum P, calculates r_1 and the coefficients k_j, κ_j, μ_{mj} and ν_{mj} corresponding to field measurements made on a polar grid in the median plane of the magnet. SEACY also calculates the average field and the flutter = $\langle \Delta B^2 / \overline{B}^2 \rangle$ at the radii for which measurements are made. So far we have used SEACY to analyze one complete set of model-magnet measurements, and have used the coefficients thus obtained with ITV to obtain a set of equilibrium orbits, periods, and the betatron frequencies. Approximate formulas have been derived by Lloyd Smith for the betatron frequencies, equilibrium orbit, period, and radial instability in terms of the Fourier coefficients defined above and calculated on the 650, and we are comparing the results obtained with these formulas with the 704 output. Where valid, such formulas are more useful than the corresponding exact 704 results for determining the necessary changes in the field shape. Recently, under the direction of Dr. T. Welton, Oak Ridge converted one of their ORACLE codes to the 704. This code does about the same thing as ITV, but it uses the measurements almost directly and is consequently much faster than ITV. We are currently preparing a 704 code to process the raw data into the form required by this code. This processing code will also calculate approximately the correction to the average field at any radius required to produce isochronism, and if desired will correct the orbit-code input accordingly. (Alper Garren)

MISCELLANEOUS THEORETICAL WORK

A short note has been published (Phys. Rev. Letters 1, 258 (1958)) on the parity to be assigned to the second resonance in single-pion photoproduction. (J. J. Sakurai)

The manuscripts for the μ-mesonic molecular-ion calculations are in the process of final revision. They will be published in the Physical Review. (Stanley Cohen, David L. Judd, and Robert J. Riddell, Jr.)

A UCRL report and a RAND research memorandum describing the self-consistent calculations carried out at the RAND Corporation have been issued.[16] These reports also contain the results for the normal mercury atom. Several additional papers containing similar results will be issued in the near future. (Stanley Cohen)

Calculations have continued on the low-temperature behavior of a dilute Bose system of hard spheres. (T. D. Lee, in collaboration with Professor C. N. Yang, Institute for Advanced Study, Princeton)

The stability of two colliding beams of electrically charged particles moving with relativistic velocities has been investigated. Generalized Ohm's laws relating the current to the effective fields have been derived under several assumptions and the question reduced to the solution of boundary-value problems. At present the applicability of variational methods to this type of problem is being studied. (Maurice Neuman)

[16] Stanley Cohen, Relativistic Self-consistent Calculation for the Normal Mercury Atom (July 1958), to be issued as a Rand report.

REDUCTION OF DATA FROM BUBBLE CHAMBERS

With the IBM 704

The IBM 704 program PANG (which was reported in the preceding progress report) has been nearly completed. The program is in the final stages of debugging, and output routines are being prepared. (Charles Stableford and Barbara Levine for Bubble Chamber Group)

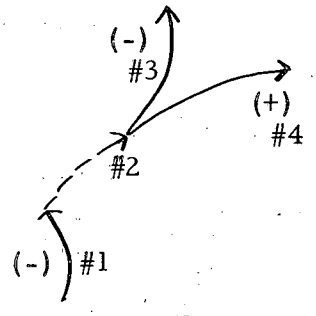
A 704 program called GUTS has been written to analyze the following five types of bubble chamber events: 0C, 1C, 2C, 3C, and 4C. An nC vertex is defined as follows: If n is an integer between 0 and 4 inclusive, then n = 4 - r, where r is the number of unknown variables at a vertex. The variables for each track are the colatitude, azimuth, and momentum. This is a 4000-word subroutine intended for use with a control program associated with a particular particle-interaction experiment. The program has no input or output routines and must be supplied with all the data necessary to perform a least-squares fit to a given interpretation of an interaction vertex. This program performs a least-squares fit on the measured momenta and angles in an event subject to the constraints of conservation of energy and momentum. The method is described by Frank Solmitz, UCRL Engineering Note 4320-60 M6. At most seven particles may be involved. (Seymour Singer for Horace Taft)

With the IBM 650

Several analysis programs for bubble chamber events have been produced.

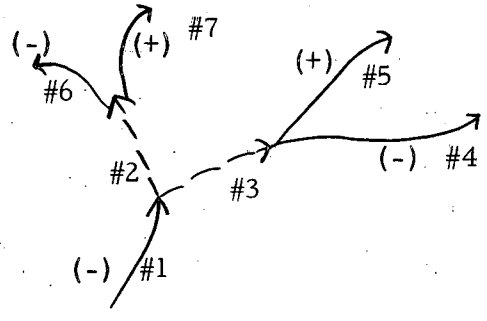
KICK I and KICK II. The purpose of the KICK programs is to analyze single- and double- V events as observed in the bubble chamber.

Single-V, Type 60



$\pi^- + p \rightarrow V^0$

Double-V, Type 50



$\pi^- + p \rightarrow K^0 + \Lambda^0$

Each V is given two interpretations,

(1) $K^0 \rightarrow \pi^+ + \pi^-$,

(2) $\Lambda^0 \rightarrow p + \pi^-$.

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KICK I determines whether the observed data in each V satisfy the energy and momentum relationships that exist between the particles. If not, KICK I determines those values which both fit the constraints and give a minimum value of χ^2. Along with the above calculation the error in each term is computed. Memory limitation in the 650 makes it necessary to end the KICK I program at this stage. KICK II now computes various items, such as the averaged dip and azimuth for Track 1; the production angle in the laboratory system; the momentum of the incident pion and its root-mean-square error; cosine of the hyperon c.m. production angle; the semimajor axis and angle of rotation from the principal axis of the error ellipse of P_x or P_Λ; the direction cosines of the negative decay product measured in the rest system of the V^0; the flight time of the particle; the potential time of the particle; the potential time of the unseen particle. These programs are described in Engineering Notes, File No. LA 5, by Lynn Stevenson. (Robert Harvey and Harold Hanerfeld for Bubble Chamber Group)

SKAP I and II. SKAP I is to analyze Type-70 events, i.e.,

$$\pi^- + p \rightarrow \Sigma^- + K^+$$

$$\Sigma^- \rightarrow \pi^- + n \ .$$

The method used was that of KICK I, with some modifications. SKAP II is the analog, for Type-70 events, of KICK II. These programs are described in Engineering Notes Memo No. 50 by Myron Good. (Robert Harvey and Harold Hanerfeld for Bubble Chamber Group)

Several additional programs have been written for the bubble chamber group. They are:

· A 650 program which combines angular-production and decay data of a $\pi^- + p \rightarrow \Lambda^0 + K^0 \rightarrow p + \pi^-$ experiment with angular-production data from a $\pi^- + p \rightarrow K^0 + \Lambda^0 \rightarrow \pi^+ + \pi^-$ (no-decay) experiment to find a best guess of the angular production and decay, together with an error matrix. (Edwin Towster for Frank Crawford)

· MALISOAPD 3 and 5, which are concerned with getting a maximum-likelihood solution to the problem of fitting three and five parameters to a theory that accounts for a distribution into 6 (for the 3-case) and 36 (for the 5-case) histograms, when the actual distribution in these histograms is given. For more details see Engineering Notes by Frank Crawford, Files No. 1 and No. 2. (Harold Hanerfeld for Frank Crawford)

· A series of programs entitled KEYSTONE, which are intended to supersede the programs referred to in the preceding report for converting HYDRO output to CLOUDY input. The KEYSTONE programs use HYDRO II output and compute certain space parameters in both fixed-point and floating-point representations. This output is used in either of two programs, TCMIE or STRETCH. TCMIE performs a transformation from laboratory to center-of-mass system for inelastic events. STRETCH determines the unknown masses in an event by a least-squares procedure. (Richard Mitchell for Bubble Chamber Group)

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· A number of programs to simulate the operation of the rapid scanner which is being developed by Bruce McCormick. The first, COCA, simulates the pulse shapes and the track-detection pulse developed from the pulse train generated by signals from the scanning-slit photomultipliers. The output, with the aid of an auxiliary program, FIX COCA, is plotted on the automatic plotter. (Richard Mitchell for Bruce McCormick)

· A general ray-tracing program to aid in the design of the optics system for the rapid reader. This program is sufficiently general for many optical-design problems. (Richard Mitchell for Bruce McCormick)

· A series of routines, KINE II A, B, and C to compute tables of kinematical quantities in two-body elastic and inelastic collisions. Both lab and c.m. quantities are computed as a function of chosen independent parameters. For KINE II A the independent parameters are the lab momentum and direction of one of the particles after collision. In KINE II B the parameters are the lab angles of both particles after collision. In KINE II C they are the c.m. scattering angle and the lab momentum of the incoming particle. (Donald Steinberg for Bubble Chamber Group)

PROGRAMS FOR 88-INCH CYCLOTRON DESIGN

The following programs were written in connection with the design of the 88-Inch Cyclotron.

SEACY -- Phase II. This program takes field values as measured in the median plane on a polar grid, and produces a Fourier representation of the measured values as a function of angle for each fixed radius. The code is capable of handling up to 15 harmonics. The flutter and average field are included in the output for each radius. Provision is made for recalculating the field in terms of the Fourier representation.

SEACY -- Phase III. For a given momentum, this program finds the equilibrium radius in terms of the average field. A weighted-least-squares fit of the Fourier coefficients to a polynomial in r of degree n is constructed; i.e., from Phase II we have

$$B_j = \sum_{k=1}^{k_{max}} \left\{ \mu_{jk} \cos k\theta + \nu_{jk} \sin k\theta \right\} \; ; \; j = 1, 2, \ldots, j_{max}.$$

Then for each k, the least-squares fit is made for

$$(\mu_{1k}, \mu_{2k}, \ldots, \mu_{j\,max\,k})$$

and

$$(\nu_{1k}, \nu_{2k}, \ldots, \nu_{j\,max\,k}).$$

Judd

The fit is weighted equally about the points μ_{jk} which correspond to the equilibrium radius. The output of this program is then used as input to a code written by MURA for the 704. The MURA code computes orbits and equilibrium orbits in a given field. (Robert Harvey for Alper Garren)

Preparations are being made to use an IBM 704 program recently obtained from Oak Ridge for computing orbits by using measured values of the magnetic field. (Robert Harvey and Ardith Kenney for Alper Garren)

Also some hand computations used in studying the magnet design for the 88-inch cyclotron were done. (Jonathan Young for David L. Judd, Lloyd Smith, and Alper Garren)

OTHER ACTIVITIES OF THE MATHEMATICIANS

A 701 program was used to find eigenvalues of the two-dimensional Schrödinger wave equation in order to determine the vibrational states of the H_2^+ electronic ion. (Victor Brady for John Hiskes)

A 650 program to compute particle orbits in the median plane of the magnetic field of a cyclotron has been written. A method of perturbing the orbits was incorporated into the program in order to study a radio-frequency system for extracting particles from a cyclotron. (Victor Brady for Warren Stubbins)

A 650 program for computing proton orbits in the median plane of the magnetic field of the Bevatron was written. This program was used to study methods of extracting the proton beam from the Bevatron. (Victor Brady for Lloyd Smith)

A 650 program to compute the vertical motion of charged particles in the magnetic field of the Bevatron was written. In order to use this program the orbit of the particle in the median plane must have been previously determined. (Victor Brady for Harold Ticho)

A 650 program to tabulate certain integrals which are of interest in the study of penetration of nuclei by antinucleons was written. (Seymour Singer for T. Kalogeropoulos)

A 650 program to analyze the propagation characteristics of a transmission line has been written. This program Fourier-analyzes the input pulse for the line and, from the output pulse, determines the absorption and phase shift as a function of the frequency. Some work remains to be done to eliminate a dependence on the length of the line in favor of a dependence on some measure of the time delay between input and output pulses. (Seymour Singer and Kent Curtis for Electrical Engineering)

A Monte Carlo program for analysis of a K-meson experiment was written. This program assumes that production of a particle is uniformly distributed in a cyclinder. The particle is given in one case an isotropic

distribution of directions and in another case a weighted distribution. If the particle escapes the cylinder before it decays, we determine whether or not either of the decay products re-enters the cylinder. (Harold Hanerfeld for Victor Cook and Robert Birge)

A 650 program, WERT, which will find the eigenvalues and eigenvectors of real symmetric matrices of orders up to 30×30 is being written. This program is designed for the 650 after augmentation by floating-point and index registers. It will replace a similar program for the basic machine. (Harold Hanerfeld for 650 Library)

The first 650 program in connection with the thermonuclear research being conducted at Berkeley has been put into effect. Information about the frequency and configuration of plasma oscillations was obtained from knowledge of the current density of the Triax tube. The magnetic field produced by current in the tube was measured as a function of time at each radial position. Computations were made to determine the current distribution

$$j(t, r) = \text{curl } B = \frac{B}{r} + \frac{dB}{dr}$$

in triaxes of cylindrical geometry. (Ardith Kenney for Wulf Kunkel and Mel Berstein)

A budget run using the program Schedule 92 was made to determine what costs were developing from certain effort predictions. The results indicate what modifications, if any, need to be made in the effort figures. (Ardith Kenney for Director's Office)

The energy spectrum of neutrons produced by 910-Mev alpha particles striking an internal beryllium target in the 184-inch cyclotron is determined from the range of protons knocked out of a scatterer by the neutrons by use of a carbon-hydrocarbon difference. Numerical calculations were made which indicate that in studying the data one may assume that the nucleons in the alpha particle interact independently of one another during the collision with the beryllium nucleus. Also a program for reduction of random errors in counting experiments was written. (Ardith Kenney for Warren Stubbins)

The program called WRETCH for generating, on the IBM 701 digital computer, solutions to the scalar Helmholtz equation

$$\nabla^2 \psi(x, y, z) + k^2 \psi(x, y, z) = 0$$

as a series of spherical Bessel's functions, which was started by David Johnson for Jack Uretsky, has been completed and checked out except for extreme values of k^2. This involved adding to the work done earlier by Mr. Johnson a print routine for printing out the two-full-word floating-point numbers used by WRETCH, and a section of coding which completes the computation and normalization of the wave functions and finally stores the Bessel's function coefficients on the drum and, if desired, prints them out together with the separation constant. Also the entire WRETCH routine was converted to a subroutine callable from the drum, and provision was

made for loading it onto the drum. In addition preparation was made to convert DULUX, the interpretive floating-point routine used by WRETCH and written by Mr. Johnson, to a subroutine callable off the drum together with the new print routine mentioned above. (Matthew White for Jack Uretsky)

Further revisions and runs have been made investigating "small" terms in cross sections for photoproduction of π^+ mesons from protons according to dispersion-relation theory. A program was written to compute similar cross sections for π^- mesons. (Marjory Simmons for Jack Uretsky)

A relocatable SOAP II subroutine was written for the 650 to compute Clebsch-Gordan coefficients, and was used to generate a considerable addition to the ORNL Table of Clebsch-Gordan coefficients. The range is limited to coefficients involving factorials less than or equal to 25!. The subroutine will be published as a UCRL report and submitted to the IBM 650 program librarian for distribution. (Marjory Simmons for John Rasmussen)

A differential-equation–eigenvalue problem was solved by using the IBM 650 differential-equation routine written by Robert Harvey. (Richard Mitchell and Jonathan Young for Richard Dalitz)

A 650 program has been written which calculates the maximum energy that a π^+ meson can attain from the reaction $\pi^+ + p \rightarrow \pi^- + \pi^+ + n$ and the maximum energy it can attain for each of several angles between 20° and 160° in the center-of-mass system. (Edwin Towster for Walter Perkins)

Two programs were written which calculate (a) Bethe-Heitler unscreened differential and total cross sections, (b) Bethe-Heitler screened differential and total cross sections, and (c) Wheeler-Lamb differential and total cross sections, all for hydrogen, but with easy program modifications for other elements. (Edwin Towster for D. C. Gates)

A program was written to help determine energy levels of excited electron states of astatine. (Edwin Towster for Ralph McLaughlin)

A 650 program to compute the roots of a fifth-order equation as a function of one parameter for use in studying transition frequencies between nuclear energy levels was written. (Alice McMullen and Edwin Towster for Alan Reddock)

A 701 program to compute high-energy (p, pn), (p, 2p) cross sections on the basis of a shell model has been written. (Alice McMullen for Paul Benioff)

A Monte Carlo treatment of neutron ejection from a compound nucleus is being written for the IBM 701. The purpose is to obtain, for each type of reaction considered, the neutron-energy spectrum and(or) the angular distribution of recoil nuclei, assuming a homogeneous angular distribution of the emitted neutrons. The calculational procedure is outlined

in a separate report.[15] This is a continuation of the work previously done by Robert Freeman for Bernard Harvey, William Wade, and Paul Donovan. (Walter Hutchinson for Paul Donovan)

A 650 program to compute the roots of algebraic equations of arbitrary degree has been written. The routine is not yet in finished form but it works well for equations of sixth degree or less. (Barbara Levine for Kent Curtis)

Programming and debugging of the IBM 701 problem ALPHONSO, a Monte Carlo calculation of high-energy reactions in heavy nuclei, continues. Detailed flow charts of all of the main program and some subroutines have been made. A program to compute differential and total cross sections for elastic and inelastic (up to 3 pions produced) nucleon-nucleon collisions in free space (formulas given by Dr. Lester Winsberg) has been debugged. An analytic test of a simplified special case for a cross section in nuclear matter is being developed. (Thomas Clements and Marjory Simmons for Lester Winsberg)

A 650 program which calculates shower products arising from the traversal through matter of high-energy electrons, which was reported in the preceding semiannual report, has been completed. (Donald Itzel for N. A. Williams and LeRoy Cook)

A 650 IBM program, MEDEA, has been written; its function is to calculate the production matrix elements of the events

$$\Lambda \rightarrow \pi^0 \rightarrow 2\gamma$$

$$\Sigma \rightarrow \pi^0 \rightarrow 2\gamma$$

$$K \rightarrow \pi^0 + \pi^0 \rightarrow 4\gamma.$$

The program employs γ-counting rates obtained from Bevatron experiments. (Donald Itzel for Sherwood Parker)

A program has been written for the IBM 701 for determination of the distribution of counter firings in a ring counter. The ring counter consists of two banks of concentric rings, the first with seven counters, the second with eight. The target is a cylinder whose axis passes through the center of the rings. A modified Monte Carlo scheme is being used to study the angular distribution of particles firing one or more counters, and the angular resolution of the system. (Jonathan Young for LeRoy Kerth and Thaddeus Kycia)

[15] Paul F. Donovan, Nuclear Reaction Mechanisms in the Heavy-Element Region, UCRL-8347, June 1958.

FORTRANSIT ROUTINE

FORTRANSIT II, a compiling routine for the IBM 650, has been studied and made available to the laboratory. Many of the subroutines commonly used at the laboratory were rewritten for use with FORTRANSIT II and the limitations and capabilities of the program studied in detail. One of the limitations of interest which was discovered is that in the punching of an array, such as a matrix G, the program can handle only a maximum of about 30 elements. A recent modification of FORTRANSIT which we have just received may remove this limitation. (Alice McMullen for Kent Curtis)

The standard load and punch routines have been modified for use with the FORTRANSIT board. The special punch program is needed because the FORTRANSIT punching program is very poor for a large matrix and, further, this dump makes it possible to stop a long-running program and restart it again at a later time. (Richard Mitchell for Kent Curtis)

Following the general availability of the FORTRANSIT compiler to the laboratory, a number of programs were written in this language by diverse persons. Our experience indicates that it can be used to advantage, even by persons completely unfamiliar with programming, for problems of moderate complexity. For very simple problems the machine time used in compiling makes the system too expensive to be practical. The following programs, written by Richard Mitchell for the persons named, are typical:

A program to determine the probability of counting particles at given angles and energies in the laboratory system from assumed center-of-mass distributions of angle and energy. (Richard Mitchell for Hoyt Bostick)

A program to compute some double integrals associated with a study of shock waves in nuclear matter. (Richard Mittchell for A. E. Glassgold)

A program to compute a set of functions from a recursion relation involving integrals of the functions. (Richard Mitchell for Bipin Desai)

Negotiations have continued with the Campus Computer Center and IBM for obtaining a 704 on the campus. The present expectation is to receive about 80 hr/week on a 704 which will be installed in the summer or early fall of 1959. The configuration that has been requested includes a 32,000-word magnetic-core memory, but this is subject to availability on the educational-discount plan. Our expectation is to receive the following configuration when the machine is first installed: 8,000-word core storage, one drum unit, eight tape units, a cathode-ray-tube unit, and an off-line printer that will use one of the eight tape units. The Laboratory will have space near the machine for card and tape storage. There will be a ready room shared by the Computer Center and the Laboratory, and an office upstairs for the Laboratory. The Laboratory has joined the SHARE organization, and work is in progress to assemble a library of 704 subroutines and an index of subroutines from the material received from SHARE. We expect to compile a "minimum package" of tested subroutines, which will be adequate for most purposes, and an index of all other routines available. The minimum package will be assembled first, and every effort will be made to insure its accuracy. A more comprehensive library will be constructed as time permits. (Kent Curtis)

Judd

PHYSICS RESEARCH

Edward J. Lofgren in charge

SEARCH FOR X-RAYS FROM K-MESIC ATOMS

Nahmin Horwitz and Joseph J. Murray

The experiment described in an earlier report[1] was run in the K^--meson beam[2] at the northwest station at the Bevatron from October 3 to October 11. A counter telescope was used to identify stopping K^- mesons; the identification was based on time of flight, range, and dE/dx requirements. Approximately 500 K mesons were brought to rest in each of the following: Li, Be, C, and H_2O. The K mesons were stopped at the rate of 0.05 K meson per 10^{10} protons on target. X-rays from the stopper were detected by a NaI counter array which covered approximately 40% of the 4π solid angle. There are faint suggestions of x-ray peaks, corresponding to the lithium L line, the beryllium L line, the carbon M line, and the oxygen M line. The peaks contain, typically, 10 to 20 x-rays, implying an upper limit of about 15% for their yields. The signal-to-noise ratio is approximately 1.

On October 11 the target failed. The experiment will continue after the target is repaired.

THE STUDY OF K^+ MESONS WITH THE 30-INCH PROPANE BUBBLE CHAMBER

Warren W. Chupp and Sulamith Goldhaber

We have continued the scanning of film taken during the exposure of the 30-inch propane bubble chamber to K^+ mesons of incident momenta of 480 Mev/c and 424 Mev/c.

This work has passed through the scanning stage and is well into the analysis part of the experiment. (The analysis would normally keep abreast of scanning, but since this undertaking is our initial venture into this type of work, much effort has been expended in obtaining and developing equipment and computer programs.)

A tentative summary of results is as follows:

(a) Pictures scanned: ~20,000.

(b) Number of K^+-meson–hydrogen scattering "candidates": ~130.

(c) Number of observed "candidates" for the charge-exchange reaction $K^+ + n \rightarrow K^0 + p$: 15.

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[1] Nahmin Horwitz and Joseph J. Murray, Detection of K-Mesic X-Rays, in Physics Division Quarterly Report, UCRL-3782, May 1957, p. 24.

[2] N. Horwitz, J. J. Murray, R. R. Ross, and R. D. Tripp, 450-Mev/c K^- and $\bar{p}$ Beams at the Northwest Target Area of the Bevatron Separated by the Coaxial Velocity Spectrometer, in UCRL-8269, June 1958, p. 31.

(d) Number of associated neutral decays associated with charge-exchange candidates: 3.

We expect that the θ_1^0 decay ($\pi^+ + \pi^-$ with mean life $\sim 10^{-10}$ sec) should be seen in approximately 38% of all charge exchanges, therefore a considerable number (~ 7) of our charge-exchange candidates are probably examples of proton-carbon scattering resulting from contamination protons in our beam. This will be resolved for the most part by our analysis.

This work is being conducted in conjunction with Gerson Goldhaber, Wilson Powell, William B. Fowler, and Joseph E. Lannutti.[3]

ASYMMETRY IN THE DECAY OF Σ HYPERONS

Rodney L. Cool,[4] Bruce Cork, James W. Cronin,[5] and William A. Wenzel

Measurements have been made of the asymmetry in the decay of Σ hyperons. The results have been prepared for publication.[6] The abstract is as follows.

A search has been made for an asymmetry in the decay of $\Sigma^\pm$ hyperons. The $\Sigma^\pm$ mesons were produced in the reactions $\pi^\pm + p \rightarrow \Sigma^\pm + K^+$. Detection and identification of the K^+ mesons by a counter technique selects the above reactions and establishes the plane of production. Additional counters, which detect the pions from the Σ-hyperon decay in coincidence with the K^+ mesons, measure the symmetry with respect to the plane of production. The results yield the parameter $\alpha\bar{p}$, where α measures the strength of parity nonconservation and $\bar{p}$ is the average polarization of the Σ hyperon. The data give: for Σ^- hyperons produced by 1.0-Bev π^-, $\alpha^-\bar{p} = +0.02 \pm 0.05$; for Σ^- from 1.1-Bev π^-, $\alpha^-\bar{p} = -0.06 \pm 0.05$; for Σ^+ from 1.0-Bev π^+, the decay mode $\Sigma^+ \rightarrow \pi^+ + n$ gives $\alpha^+\bar{p} = +0.02 \pm 0.07$, and the mode $\Sigma^+ \rightarrow \pi^0 + p$ gives $\alpha^0\bar{p} = +0.70 \pm 0.30$. The value of $\alpha^0\bar{p}$ for $\Sigma^+ \rightarrow \pi^0 + p$ strongly indicates that parity is not conserved. For the Σ^+, $\bar{p} \geqslant 0.70 \pm 0.30$; thus we can conclude $|\alpha^+| \leqslant 0.03 \pm 0.11$. The results therefore indicate that the asymmetry parameter α depends upon the isotopic spin states in the final pion-nucleon system. The dependence on the isotopic spin is compatible with the $|\Delta I| = 1/2$ rule.

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[3] Now at Florida State University.

[4] On leave of absence from Brookhaven National Laboratory.

[5] Now at Palmer Physical Laboratory, Princeton University, Princeton, N. J.

[6] R. L. Cool, Bruce Cork, James W. Cronin, and William A. Wenzel, Asymmetry in the Decay of Σ Hyperons (submitted to Physical Review).

MEASUREMENTS OF ANTIPROTON INTERACTIONS AT HIGH ENERGY

Rafael Armenteros,[7] Bruce Cork, Charles A. Coombes, Glen R. Lambertson, and William A. Wenzel

The general features of this experiment have been described elsewhere.[8] This experiment, to be performed at $\bar{p}$ momenta 1.4 to 3 Bev/c, includes measurement of elastic-scattering, charge-exchange, annihilation, and other inelastic cross sections for p-$\bar{p}$ interaction. In addition, an attempt will be made to detect neutral hyperons and antihyperons produced by reactions of the form

$$p + \bar{p} \rightarrow Y^0 + \bar{Y}^0.$$

As a preparation for this experiment, the trajectories of high-energy antiprotons produced in a target located in the curved section of the Bevatron have been determined. Also, a second parallel-plate spectrometer has been built and operated at 400 kv.

To reject pions at very high momenta, 3 Bev/c, a 60-in.-long gas Cherenkov counter has been built. Two mirrors and Lucite lenses bring the radiation out to 2-in.-diameter photomultipliers. The efficiency for counting 3.0-Bev/c pions, when the counter is filled with CO_2 at a gas pressure of 150 psi, is greater than 98%. The additional counters and electronics for this experiment have been designed and are being built.

K^--d INTERACTIONS

Nahmin Horwitz and Joseph J. Murray

Analysis of K^--meson interactions in deuterium, which were detected in the 15-inch bubble chamber, is in progress.[9]

K^--meson absorptions which lead to $\Sigma^0 + \pi^- + p$ have been separated by a kinematic analysis from those which lead to $\Lambda^0 + \pi^- + p$. The analysis of these events has produced evidence for the following two-step process. First the K^- meson is absorbed by a single nucleon to produce a Σ hyperon and a π^- meson. Next the Σ interacts with the remaining nucleon and converts to a Λ^0. Further, the conversion occurs 40% of the time that the initial absorption produces a Σ and a nucleon in an isotopic spin-1/2 state. This information is to be presented at the Chicago meeting of the American Physical Society.[10]

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[7] On leave from Ecole Polytechnique, Paris, France.

[8] Cool, Coombes, Cork, Lambertson, and Wenzel, in Physics Division Semiannual Report, UCRL-8281, May 1958, p. 36.

[9] Refer to the progress reports of the Alvarez Group in this issue for more information.

[10] N. Horwitz, D. Miller, J. J. Murray, M. Schwartz, and H. D. Taft, K^- Absorption in Deuterium I: Evidence for the Two-Step Process, $K^- + D \rightarrow (\Sigma + \text{Nucleon}) + \pi^- \rightarrow (\Lambda + \text{Nucleon}) + \pi^-$, UCRL-8462 (Abstract), Sept. 1958.

SEARCH FOR A PARTICLE IN THE MASS BAND 450 m_e TO 650 m_e*

Sulamith Goldhaber

We have completed the scanning of a nuclear emulsion stack exposed to a beam of positive mass-selected particles, described in the preceding report.[11] The mass was selected by using a system giving magnetic analysis followed by velocity analysis. The latter consisted of Murray's coaxial velocity selector, which rejected pions at a ratio of 100 to 1. In the course of the exposure, 10^7 pions entered the system. The principal momentum channel was 250 Mev/c.

The scanning procedure consisted of selecting particles of a given ionization on entering the stack and following them until they either interacted or came to rest. The background consisted of (a) low-energy pions and muons that scattered into the stack, (b) pions and muons of the principal momentum channel that were not rejected by the separator, and (c) low-energy electrons. Group (a) consisted of 41 pions and 42 muons. In this group, one particle was found which gave a higher apparent mass value than that of a pion. A large effort went into making meticulous mass measurements on this particle and on calibration tracks.[12] Particles from Groups (a) and (b) were used for calibration.

The particle under question, which we will refer to as Particle X, traversed a distance of 4.9 cm in the stack, after which it apparently came to rest. It then decayed into a μ meson of 614-micron track length which in turn decayed into a "positron." Thus, from the decay characteristics, particle X would appear to be indistinguishable from a π^+ meson. Any evidence that the observed event may be due to a particle other than a pion is based solely on direct mass measurements on the primary track of Particle X.

The mass measurements performed fall into three categories:

1. Ionization range
2. Multiple-scattering ($p\beta$) range
3. Energy of δ rays

Mass measurements were carried out as briefly described below. All errors quoted are statistical errors only.

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*The mass measurements described in this report were carried out in cooperation with Joseph E. Lannutti, now at the University of Florida, Tallahassee, Florida.

[11] Goldhaber, Murray, Horwitz, and Caldwell, in Physics Division Semiannual Report, UCRL-8281, May 1958, p. 38-39.

[12] These measurements were performed by T. F. Hoang, on leave from the Ecole Polytechnique, Paris, France and now at the Lawrence Radiation Laboratory, Berkeley.

1. Ionization Range

Four different types of ionization range measurements were made, giving mass values

A. 352 ± 10

B. 347 ± 15

C. 382 ± 25

D. 383 ± 25

Owing to the statistical grain distribution, the errors quoted cannot be combined directly, since they are not independent. Determinations A and C are based on grain-count range measurements. Determinations B and D are based on the Fowler-Perkins gap-coefficient method. In measurements A and B we calibrated directly against low-energy pions, assuming uniform development throughout the stack. In measurements C and D we calibrated against low-energy pions through the intermediary of near-minimum ionizing particles (of measured identity and range) found in the immediate vicinity of the track. This type of measurement should elimate errors introduced because of nonuniformity in development.

2. Multiple-Scattering Range

In this measurement, a careful calibration against pions of similar dip was carried out. Caution was taken to eliminate errors in the $p\beta$ measurements due to distortion. A mass value of $391 \pm 40\ m_e$ was obtained by this method.

3. Energy of δ Rays

A crude mass determination on particle X_{12} by determining the energy of three δ rays observed along the track, gave the following upper limits to the mass:

$$M_x = 353^{+222}_{-\ 89},\quad M_x = 565^{+255}_{-112},\quad M_x = 635^{+100}_{-\ 70}.$$

Conclusions

The event described above must correspond to either a very large fluctuation of both the ionization and multiple scattering of a π meson, or to a new particle. Since the apparent mass values of this event fall between that of a pion and that of the particle described by Alikhanyan et al., the type of fluctuation described above could be on the ionization and $p\beta$ of either of the two particles. It should be noted that the observed decay into a μ meson with a 614-micron track can be the consequence of the decay of particle X into a low-energy pion before it comes to rest. The track was carefully examined for a possible decay point of that type. Such a decay in the last 500μ of track could however, have, remained undetected. The event reported here does not allow us to decide between the two alternatives.

Lofgren

PHYSICS RESEARCH

Burton J. Moyer in charge

ENERGY SPECTRA AND ANGULAR DEPENDENCES OF NEUTRONS FROM THE 31.5-Mev PROTON BOMBARDMENT OF BERYLLIUM-9, NITROGEN-14, AND ALUMINUM-27

H. E. Adelson, H. A. Bostick, and C. N. Waddell

The reading and analysis of the data from the 4-inch hydrogen bubble chamber have been completed. The neutron spectra for energies greater than 5 Mev were measured at 53°, 90°, and 127°(lab) for each of the three targets. For all the targets the neutron production was peaked forward, indicating a reaction mechanism of the direct-interaction type, i.e., an interaction in which the outgoing neutron is emitted before the available energy has been shared to a large degree with other nucleons in the nucleus.

The energy spectra from the bombardment of Be^9 and N^{14} contain structure corresponding to known levels of the residual nuclei, B^9 and O^{14}, from the (p, n) reaction. There are also some neutron groups which may indicate possible new levels of these residual nuclei.

The 4-inch hydrogen bubble chamber, when coupled with a fast coordinate-measuring device (Benson-Lehner OSCAR) and the IBM 650 computer, has proven to be a useful neutron spectrometer with good resolution (~10%) and high efficiency (~5%) in the 5- to 30-Mev neutron range.

PROTON ENERGY SPECTRUM PRODUCED BY PHOTONS AT 240 ± 15 Mev ON CARBON

Robert J. Cence and Gilbert Mead

A counter, as previously described, was developed to select a narrow energy band of photons from the continuous spectrum produced by the synchrotron. The energy band selected is 240 ± 15 Mev.

The energy spectrum of protons produced by this narrow energy band of photons bombarding a carbon target at 60° was measured. The data are now being analyzed with the object of obtaining information about the high-momentum components of the nucleons inside the carbon nucleus.

CHERENKOV COUNTER OF n = 1.01 TO 1.20

Wilmot N. Hess

In connection with the antineutron experiment recently performed by Professor Moyer's group, a Cherenkov counter of index of refraction n = 1.10 has been developed to aid in the identification of antineutrons. This counter uses Freon 13 ($CClF_3$) and operates near the critical point in

order to get the desired density. Typical operating conditions were P = 600 psi and T = 95°F. By varying the density a continuous change of index of refraction from n = 1.00 up to n = 1.20 can be attained. The upper limit n = 1.20 is reached when the Freon is a liquid at 30°F. The counter was checked in a 2-Bev π^- beam and found to be at least 85% efficient at n = 1.01.

Experimental data were obtained, giving the index of refraction of the Freon 13 as a function of density, by means of an investigation, at a temperature above critical, of the interference fringes produced by a Fabry-Perot interferometer mounted within the gas. A count of the fringes as the gas was introduced into the vessel, beginning with a vacuum condition, with the temperature maintained above critical gave a continuous set of data of the refractive index versus density ranging essentially from 1.0 up to 1.2.

COSMIC-RAY NEUTRON EXPERIMENT

Wilmot N. Hess, H. Wade Patterson, Roger W. Wallace, and Edward L. Chupp

Measurements are being continued in an attempt to determine the low-energy part of the cosmic-ray neutron-energy spectrum. A gold foil array covered with bismuth has been exposed at 14,000 feet on White Mountain and the 2.7-day activity counted on a pulse-height analyzer. This array will shortly be calibrated at a Livermore reactor. This gold foil detector will give a measurement of the cosmic-ray neutron flux at 4 ev, and will help settle the previously mentioned discrepancy at the low-energy end of the spectrum.

NEUTRON CROSS-SECTION MEASUREMENTS AT THE BEVATRON

John H. Atkinson, Jr., Wilmot N. Hess, Victor Perez-Mendez, and Roger W. Wallace

Cross-section measurements for 5 ± 1-Bev neutrons have been made in good and poor geometry for carbon and copper. The elastic cross sections here are less than at 1.4 Bev. This decrease indicates an increased nuclear transparency. This is reasonable, sine the nucleon-nucleon cross sections have also decreased in the interval from 1.4 Bev to 5 Bev. We are now preparing to measure the neutron-proton total cross section at this energy.

NUCLEAR EXCITATION FROM μ^- CAPTURE IN MEDIUM AND HEAVY NUCLEI

Selig Kaplan

The experimental work reported in April is still in progress. We had short runs at the cyclotron in July and August, at which times the large liquid-scintillator tank was used. It was capable of operating at a beam level corresponding to a μ^--meson stopping rate of 3 per minute. Comparison of multiplicity values measured to date with cosmic-ray results indicates the presence of a noninteracting contaminant in the cyclotron μ^- beam. We now think we understand the cause and hope to eliminate it on our next run, scheduled for December.

ANTINEUTRON EXPERIMENT

B. J. Moyer

In the preceding Semiannual Report a description was given of an experiment to be carried out which would seek to identify a beam of antineutrons in a geometry suitable for total-cross-section measurements. This proposed experiment has recently been accomplished, with results that appear generally successful so far as the data have been analyzed.

The system for identifying the antineutrons consisted of the following elements in sequence as encountered by a particle emerging from the target of the Bevatron:

1. A collimation channel aimed directly at the target at an angle of 15 degrees from the forward direction selected neutral entities (neutrons, photons, antineutrons) emerging from the target.

2. Two anticoincidence scintillation counters separated by a space of 6 ft were placed in the beam defined by the collimation.

3. Following the second anticoincidence counter was a charge-exchange volume of heavy water in the form of a Cherenkov counter whose pulse characteristics were to distinguish between the small pulses due to charge exchange and the larger pulses associated with stars and close collisions producing mesons.

4. Following the charge-exchange counter were a scintillation counter, S_1, and a discriminating Cherenkov counter. The scintillation counter provided a zero-time signal for subsequent flight-time measurements, and the discriminating Cherenkov counter provided a threshold for response such that π mesons and K mesons in the momentum interval to be subsequently accepted would register themselves and would actuate an anticoincidence signal, whereas particles of protonic mass in the accepted momentum interval would not register themselves.

5. The particles then passed into a magnetic system consisting of a quadrupole and a bending magnet whose purpose was to form images--dispersed according to momentum--of the charge-exchange counter in which antiprotons were to originate. The momentum interval selected ranged from 0.7 to 1.5 Bev/c.

6. Along the locus of the image positions thus defined was located an array of four terminal counter systems, each consisting of a scintillation counter and a large lead glass Cherenkov counter. The scintillation counter, together with the signal from S_1, provided time-of-flight information which helped to reject pions and K mesons. The lead glass Cherenkov counter provided a large pulse response, owing to the annihilation of the antiprotons that were absorbed in the medium of the glass.

The most serious type of background encountered was due to the very intense flux of high-energy photons from production of neutral mesons in the Bevatron target. The conversion of these photons in the pole faces of the quadrupole and bending magnet yielded electrons which produced shower pulses in the terminal counters in accidental coincidences with other background events in the earlier counters of the system so that they simulated the signature of antiprotons produced by charge exchange in the appropriate manner. The installation of another threshold Cherenkov counter just following the magnetic system proved highly useful in rejecting these electrons from consideration. Output pulses from all the counters were recorded by means of a distributed gate system and a four-gun oscilloscope, so that a visual presentation of the signature of an eligible event could be studied and carefully measured for appropriate flight-time and pulse-height criteria.

These studies are now in progress and the results are hopeful. The latter part of the run was given over to an attempt to measure attenuation cross sections for the carbon nucleus with respect to antineutrons, and the information on this attempt is in the process of emergence.

PHYSICS RESEARCH

Wilson M. Powell in charge

CASCADE-PARTICLE PRODUCTION

The scanning and analysis for cascade particles of approximately 50,000 pictures taken in a 5-Bev/c π^- beam with the 30-inch propane bubble chamber was completed during this period. A report is being prepared and will be issued during the following period. At this time two Ξ^- have been observed. This implies a cross section for production of cascade particles at this energy of only a few microbarns. A reproduction of the best of these cases appears in the 1958 CERN Conference Report.

ANTIPROTON STUDIES (IN COOPERATION WITH THE SEGRÈ GROUP)

The 450 cases of antiproton interactions observed in the 30-inch propane bubble chamber were carried through final scanning, measurement, and data-reduction stages. The events are now being sorted into cases of annihilation in carbon and in hydrogen, and within our ability to distinguish, these two cases cross sections will be determined. The detailed properties of the annihilation process will be displayed by the multiplicities, the momentum spectrum, and the angular distribution of the reaction products. The one definite case of charge exchange of an antiproton into an antineutron (followed by annihilation of the antineutron in the propane) was reported at the 1958 CERN Conference and appears in the report of that meeting.

POLARIZATION OF PROTONS FROM Λ^0 DECAY

Negative pions of 5 Bev/c momentum were used to produce Λ^0 hyperons in the 30-inch propane chamber. As part of the analysis of this experiment we have studied the polarization of the proton from the Λ^0 decay.

Previous experiments have determined that the product of the transverse polarization P of the Λ^0 decay and the asymmetry parameter α of the angular distribution should be about 0.8. However, the sign of α is not known.

Lee and Yang have pointed out that the longitudinal polarization of the decay proton in the center of mass of the Λ measures $-\alpha$. The transformation to the laboratory system makes some of this longitudinal polarization into transverse polarization, which can be measured by the scattering asymmetry of the protons on carbon and hydrogen in the bubble chamber.

Two hundred and fifty events, appearing to be V_0 events, with prongs scattering in the propane, have been analyzed with the purpose of determining the sign of the polarization of the proton in Λ decay. Of these only 35 were useful for this purpose; the others were neutron-induced events of θ_1^0's. The result is not conclusive, but the indication is that the sign is such that the proton has negative helicity, giving $\alpha > 0$.

CHARGE EXCHANGE OF K^+ MESONS

Robert W. Birge, Robert E. Lanou, Jr., and Marian N. Whitehead

A counter experiment has been performed in an attempt to investigate the apparent discrepancy indicated by previous experiments[1,2] in the relative rates of K^+-meson disappearance and K_1^0-meson appearance via the charge-exchange reaction $K^+ + n \rightarrow K^0 + p$. By use of a counter arrangement that detected the disappearance rate for K^+ and the charged decay of K_1^0, these rates were measured at K^+ energies of 175 Mev, 200 Mev, and 250 Mev in several different substances. Analysis of the data is still incomplete, but preliminary results are reported in two abstracts submitted for the forthcoming meeting of the American Physical Society in New York, as follows.

Charge Exchange of K^+ Mesons (I)

Marian N. Whitehead, Robert W. Birge,
L. T. Kerth, and Robert E. Lanou, Jr.

The apparent charge exchange of K^+ mesons in nuclear emulsion has been seen at energies of 50 to 300 Mev. We have previously reported the charge exchange of the K^+ to K_1^0 (short-lived) observed in the propane bubble chamber. However, the similar observation of $K^+ \rightarrow K_2^0$ (an event in which a K^+ disappears and no neutral decay is seen) is difficult because it involves definite identification of the K^+.

To measure the cross section for both of these processes, a counting scheme has been devised that measures the total disappearance rate of K^+ in a target and the charged decay of K_1^0. As a calibration the mean free path for the production of K_1^0 and K_2^0 was measured by using nuclear emulsion as a target in the counter array at 170 Mev and at 230 Mev. We find, for 170 Mev, $\lambda(K_1^0) = 428 \pm 128$ cm, $\lambda(K_2^0) = 475 \pm 50$ cm; and for 230 Mev, $\lambda(K_1^0) = 440 \pm 65$ cm, $\lambda(K_2^0) = 475 \pm 30$ cm.

Charge Exchange of K^+ Mesons (II)

Robert E. Lanou, Jr., Robert W. Birge,
L. T. Kerth, and Marian N. Whitehead

Previous experiments to produce K_1^0 mesons by the charge exchange of K^+ mesons in complex nuclei resulted in fluxes of K_1^0 mesons lower than expected. One of the experiments utilized tungsten in a multiplate cloud chamber; the other utilized carbon in a propane bubble chamber. We have now (using the counter scheme mentioned in Abstract I) measured the cross section for the production of K_1^0 and K_2^0 for 230-Mev K^+ mesons incident on tungsten. Preliminary analysis of the data gives $\sigma(K_1^0)=124\pm29$ mb, $\sigma(K_2^0)=130\pm19$ mb. Results will also be presented on the cross sections in carbon and copper and from a CD_2-CH_2 subtraction.

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[1] Lanou, Birge, Courant, and Whitehead, Bull. Am. Phys. Soc. 3, 24 (1958).

[2] Whitehead, Birge, Fowler, Lanou, and Powell, Bull. Am. Phys. Soc. 3, 24 (1958).
Powell

DATA ANALYSIS

Howard White has completed the following items in data analysis.

With the IBM 650:

1. Programing has been completed for the reduction of X-Y measurements of film from the 30-inch chamber to yield angles and momenta. Approximately 6,000 origins have been processed through these programs in this half year.

2. Programing has been revised and extended for the identification and analysis of certain types of events. Event types involved include neutral V decays with or without production origins visible in the chamber, elastic scatterings, and inelastic two-body final-state reactions. Special-purpose calculations for the Lambda-polarization experiment and for the antiproton experiment have been programed and performed.

3. Programing has been developed for detecting and removing errors due to an incorrect digitizer readout. All data currently being processed are checked by this program.

With the IBM 704:

1. The planning of programing for the reduction of the X-Y measurements has been completed, and the programing itself is now in progress.

2. Programing has continued for the identification and analysis of events. Coding is now almost complete, and debugging is to begin very soon.

An analysis has been performed of the principal nonsystematic errors found in the data obtained from photographs from the 30-inch chamber. Results indicate that some components may be detected and removed from individual track measurements by proper analysis techniques. Adaptation to machine programing is now being made.

The relative efficiency and accuracy of digitized microscope operated by a fairly large group of operators having varying degrees of training has been partially evaluated. Preliminary results indicate that a homogeneous group of operations can be obtained without severe selection. This is interpreted as indicating that the measurements are quite objective.

SCATTERING OF K^+ MESONS BY PROTONS AND NEUTRONS

R. G. Baender, Leroy T. Kerth, and Thaddeus F. Kycia

The experiment was done in July and August, 1958. From the data that have already been reduced we drew conclusions contained in the following abstracts. These will be presented at the New York meeting of the American Physical Society.

1. A monentum-separated K^+-meson beam was obtained with two strong-focusing analyzing magnets. The K^+ mesons were identified by four scintillation counters by time of flight. Confusion with π mesons was minimized by requiring an anticoincidence of a velocity-threshold Cherenkov counter. The π-meson and proton contamination of the identified K^+ mesons was estimated to be much less than 1%. From the scattering data of K^+ mesons on a 6-inch-long liquid hydrogen target we obtained the preliminary total cross sections given in Table I.

Table I

Total (K^+, p) Cross Sections

K^+ energy (lab) (in Mev)	175 ± 25	225 ± 25	275 ± 25
σ (in millibarns)	16.4 ± 1.4	14.6 ± 1.2	15.6 ± 1.4

Fifteen annular scintillation counters behind the target indicated the angle of the scattered K^+ meson or the recoil proton. The two types of particles are identified by range. Preliminary data on the angular distribution of the K^+ mesons indicate a slight forward peaking. The total (K^+, n) cross section obtained from scattering off carbon and CD_2 will also be presented.

2. An analysis similar to that used by Case and Pais for nucleon-nucleon scattering has been carried out for K^+ mesons scattered by protons. Short-range potentials of the form

$$\frac{1}{x}\frac{d}{dx}\frac{e^{-x}}{x}$$

for the spin-orbit potential and a central potential of the form $\frac{1}{x}e^{-x}$ were used. Experiment shows the curve for the total cross section to be rather flat with K^+ meson energy up to about 2 Bev. The relative strengths of the central potential and the spin-orbit potential are adjusted to fit the total-cross-section data. The angular distribution given by these potentials can be compared with experiment. Reasonable agreement with the preliminary data is achieved.

REPORT ISSUED

Wilson M. Powell, William B. Fowler, and Larry O. Oswald, A 30-Inch Propane Bubble Chamber, UCRL-8277, May 1958.

EQUIPMENT

Engineering Run of 30-Inch Propane Bubble Chamber

Great improvement in the optics of the 30-in. propane bubble chamber has been achieved by blocking off the area around the inner chamber so as to prevent the rising of convection currents of hot oil from below the chamber into the space above. Average pictures show a fivefold improvement with respect to distortions arising from these convection currents. Curvatures caused by all distortions on long tracks are now on the order of 300 reciprocal meters.

Rapid Cycling and Heavy-Liquid Operation of 12-Inch Propane Bubble Chamber

The 12-inch propane chamber was modified by David L. Bugg for operation at a fast repetition rate for use at the cyclotron. The idea is to use counter control of the lights so that greater efficiency can be achieved. The chamber was successfully run at 3 pulses per second (for short intervals only, because of the limited capacity of the compressor).

Use of a heavy liquid for improved γ-ray detection efficiency was also checked. Operation with Freon 12B at 28°C and a recompression pressure of 400 psi proved satisfactory, and this was the liquid in use when the rapid cycling was tried.

Automatic Track Measurement

The mechanical work on a "Franckenstein" measuring projector has been completed.

PHYSICS RESEARCH

Emilio Segrè in charge

PION-PROTON SCATTERING CROSS SECTIONS

James H. Foote, William Johnson, Ernest Rogers, Herbert M. Steiner, Clyde Wiegand, and Tom Ypsilantis

An experiment designed to measure the differential elastic cross section of π^+ mesons on protons and the total cross section of both π^+ and π^- mesons on protons at several meson energies is now in progress.

For the purpose of this as well as other experiments a high-intensity meson beam has been formed by using the external proton beam of the 184-inch cyclotron (Fig. 1). The size of the pion beam is 2-3/4 in. horizontally by 2 in. vertically, with momentum resolution ± 2%. The flux is 10^6 particles per sec for 312-Mev π^+ mesons and drops to 2×10^5 at 400 Mev. At 312 Mev the beam is composed of 96% π^+ and 4% μ^+ mesons.

This beam should permit good differential cross-section measurements at energies up to 450 Mev, and total cross-section measurements up to 550 Mev for π^+ mesons, slightly lower for π^- mesons.

No results are available at this time.

NEUTRON-PROTON SCATTERING CROSS SECTION

Rudolf R. Larsen

Following a suggestion by Chew,[1] preparations have been completed to measure the n-p differential cross section in the neighborhood of 180° center-of-mass angle.

The neutron beam will be produced by charge-exchange scattering of the 740-Mev proton beam on the neutrons in a liquid deuterium target. The neutron flux thus produced will be measured by performing a second charge-exchange scattering on a second deuterium target. The successive scatterings are identical and thus give a measurement of the square of the n-p charge-exchange cross section at 180° in deuterium.

Liquid hydrogen will then be substituted for the second deuterium target and the knock-on protons will be detected by a counter telescope consisting of scintillators and a velocity-selecting Cherenkov counter.

This experiment is expected to start early in 1959.

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[1] Geoffrey F. Chew, A Proposal for Determining the Pion-Nucleon Coupling Constant from Nucleon-Nucleon Scattering, UCRL-8283, May 1958.

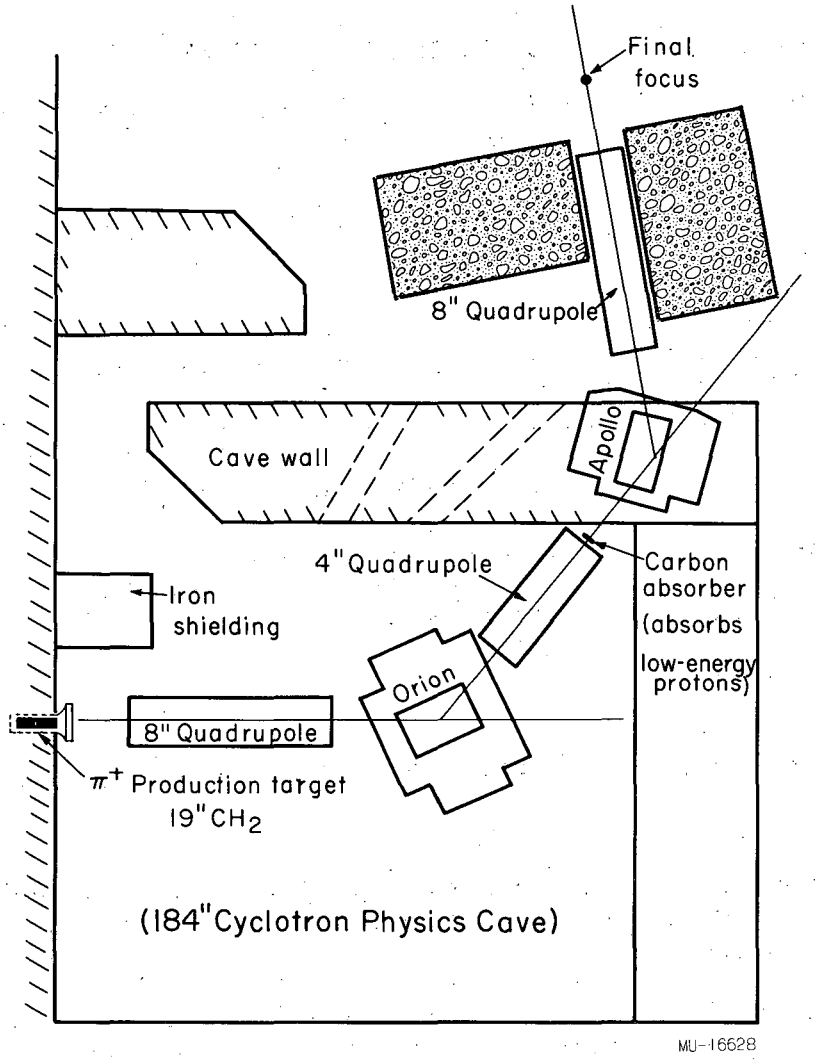

Fig. 1. Magnet arrangement for high-energy high-intensity π^+ beam.

DEUTERON POLARIZATION

Janice Button

Studies have been made of the cross section and polarization in scattering of 415-Mev deuterons by beryllium and carbon. A double scattering was done for each element with an internal target at two different positions and an external target in the physics cave.

The deuteron, a spin-one particle, has a second-scattering cross section of the form

$$I_p = I_0 (1 + d + e \cos \phi + f \cos 2\phi),$$

where I_0 is the cross section for unpolarized scattering, ϕ is the azimuthal angle between normals to the two scattering planes, d and f are products of "tensor components of polarization," and e includes also the usual "vector polarization" as well as a tensor-polarization component. Expectation values of four operators in the deuteron spin space are needed in addition to the unpolarized cross section to specify completely the scattering matrix. Two of these, contained in d and f above, could be determined immediately from differential cross-section measurements (as was done by Baldwin et al,[1] who found them indistinguishable from zero at 100 to 150 Mev); the other two are combined in the e coefficient and could be separated only by two experiments with different degrees of magnetic bending between first and second targets. This was accomplished by using a left- and a right-scattered internal beam with the same scattering angle and energy in both cases, but with very different amounts of bending in the magnetic field of the cyclotron. (See Fig. 2.)

For high energy and optimum polarization, the internal targets were located at a radius of 81 in. with scattering angle equal to 11 deg in magnitude. Six quantities--the e, d, and f parameters for the two different polarized beams--were determined by making measurements at four ϕ values for each scattering angle θ. (See Figs. 3a and 3b.) From these the four polarization components were extracted by use of an IBM search program to obtain a best fit through minimizing the quantity

$$M = \left(\frac{x_{calc} - x_{exp}}{\Delta x_{exp}} \right)^2 ,$$

with x = e, d, f, e', d', and f'. Consistency of results for carbon and for beryllium was checked by comparing calculated to experimental quantities for beryllium-carbon double scatterings.

An attempt to eliminate systematic errors and magnetic field effects was made by performing the first scattering in the steering magnet in the cyclotron exit channel, but this proved unfeasible because of dilution of polarization by a high-energy tail.

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[1] Baldwin, Chamberlain, Segrè, Tripp, Wiegand, and Ypsilantis, Phys. Rev. 103, 1502 (1956).

Segrè

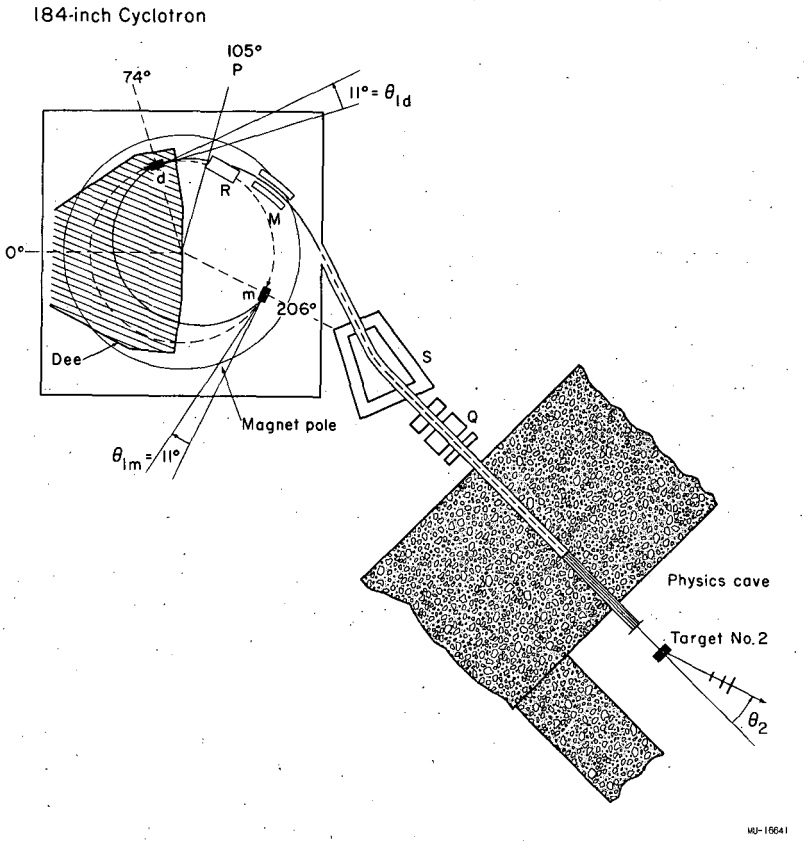

Fig. 2. Diagram of cyclotron, showing positions of dee and meson targets used to send into the physics cave two scattered deuteron beams of greatly different degrees of tensor polarization. d-Dee target (left-scattering), m-meson target (right-scattering), R-regenerator, M-magnetic channel, S-steering magnet, Q-4-inch quadrupole magnet, P-105° probe, used to position copper block with hole to pass scattered beam.

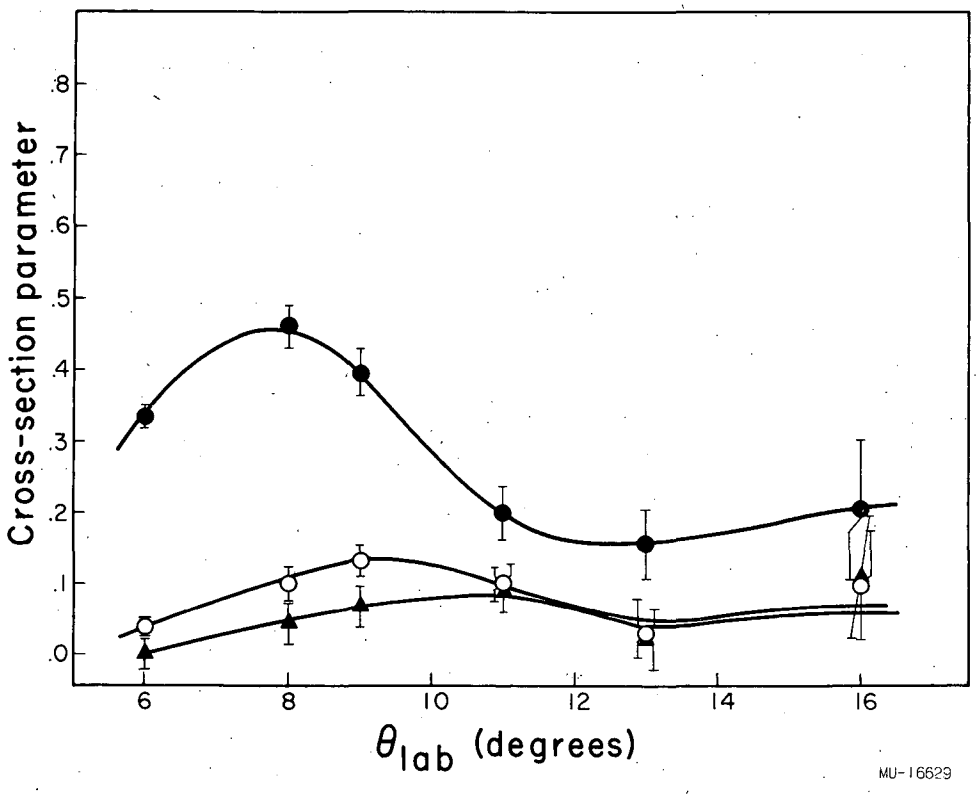

Fig. 3a. Cross-section parameters for scattering of 422-Mev deuterons by carbon: dee target. I_u is the unpolarized cross section, and ϕ is the azimuthal angle between normals to the two scattering planes. Errors are statistical only.

$$I_p(\theta_2) = I_u(\theta_2)[1 + d + e\cos\phi + f\cos 2\phi]$$

$$= I_u(\theta_2)[1 + \langle T_{20}\rangle_1 \langle T_{20}\rangle_2 + 2(\langle iT_{11}\rangle_1 \langle iT_{11}\rangle_2 - \langle T_{21}\rangle_1 \langle T_{21}\rangle_2)\cos\phi + 2\langle T_{22}\rangle_1 \langle T_{22}\rangle_2 \cos 2\phi\,] .$$

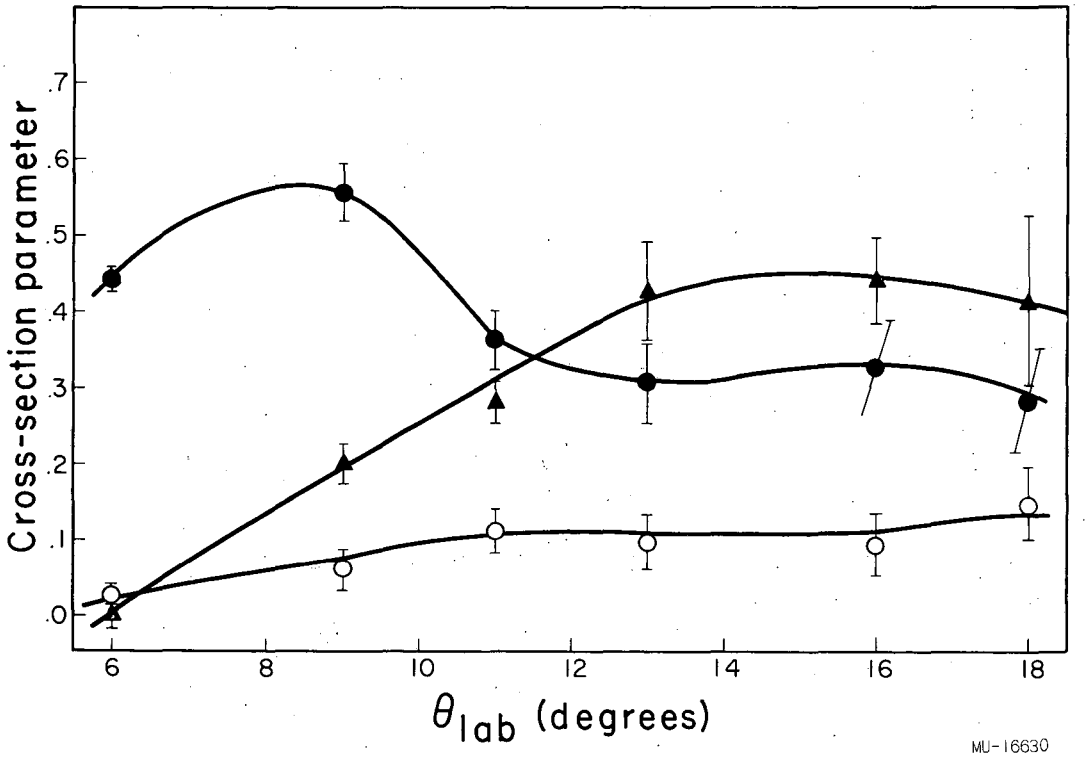

Fig. 3b. Cross-section parameters for scattering of 422-Mev deuterons by carbon: meson target. I_u is the unpolarized cross section, and ϕ is the azimuthal angle between normals to the two scattering planes. Errors are statistical only. $I_p(\theta_2) = I_u(\theta_2)[1+d+e\cos\phi+f\cos 2\phi]$.

The impulse approximation, as developed by Stapp,[2] was used to estimate cross sections and polarizations on the basis of nucleon-scattering data at 220 Mev.[3] Inclusion of the deuteron d state in the "sticking factor" was found to affect the results only slightly, but calculations including simultaneous scattering, as well as individual nucleon-nucleus interaction, of the two nucleons of the deuteron gave improved agreement with cross-section measurements and almost exact agreement with determinations of vector polarization or $\langle S_n \rangle$. Comparison of these theoretical results with the less successful polarization estimations by Baldwin indicates the greater validity of the Born approximation at higher energies. Results from Born-approximation calculations (assuming phases of nucleon-scattering amplitudes constant with angle) are compared to preliminary experimental data in Figs. 4, 5a, and 5b. It is expected that a WKB analysis of nucleon scattering data with the use of a Woods-Saxon potential will give better agreement with deuteron-scattering cross sections.

POLARIZATION OF THE RECOIL PROTON IN π^+-p SCATTERING AT 310 Mev

Owen Chamberlain, James H. Foote, Edmund Rogers, Herbert M. Steiner, Vik, Clyde Wiegand, and Tom Ypsilantis

One run has been completed, with very encouraging results. A second run may have been finished by the time this report is issued. It is hoped that this will complete the bulk of the experimental work at this energy. This experiment makes use of the high-intensity high-energy beam of positive pions developed by this group.

The apparatus used in this experiment was shown schematically in the preceding Semiannual Report on page 49. The magnet system for the pion beam is shown in Fig. 1 of this report.

Experimental results from the first run and possible curves of polarization versus center-of-mass scattering angle are shown in Fig. 6. The 113.5° points are somewhat inconsistent. The curves are calculated from phase shifts determined by differential cross-section measurements. The sets of phase shifts used to calculate these curves are as follows:

Curve 1. Russian 307-Mev S-P shifts, Fermi-type shifts (CERN Symposium 1956, Vol. 2).

Curve 2. Russian 307-Mev S-P-D shifts (CERN Symposium 1956, Vol. 2).

Curve 3. Yang-type shifts corresponding to Fermi S-P shifts, somewhat similar to those used in Curve 1.

Curve 4. Yang-type set of shifts corresponding to Curve 1.

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[2] H. P. Stapp, Phys. Rev. 107, 607 (1957).

[3] E. M. Hafner, Phys. Rev. 111, 297 (1958).

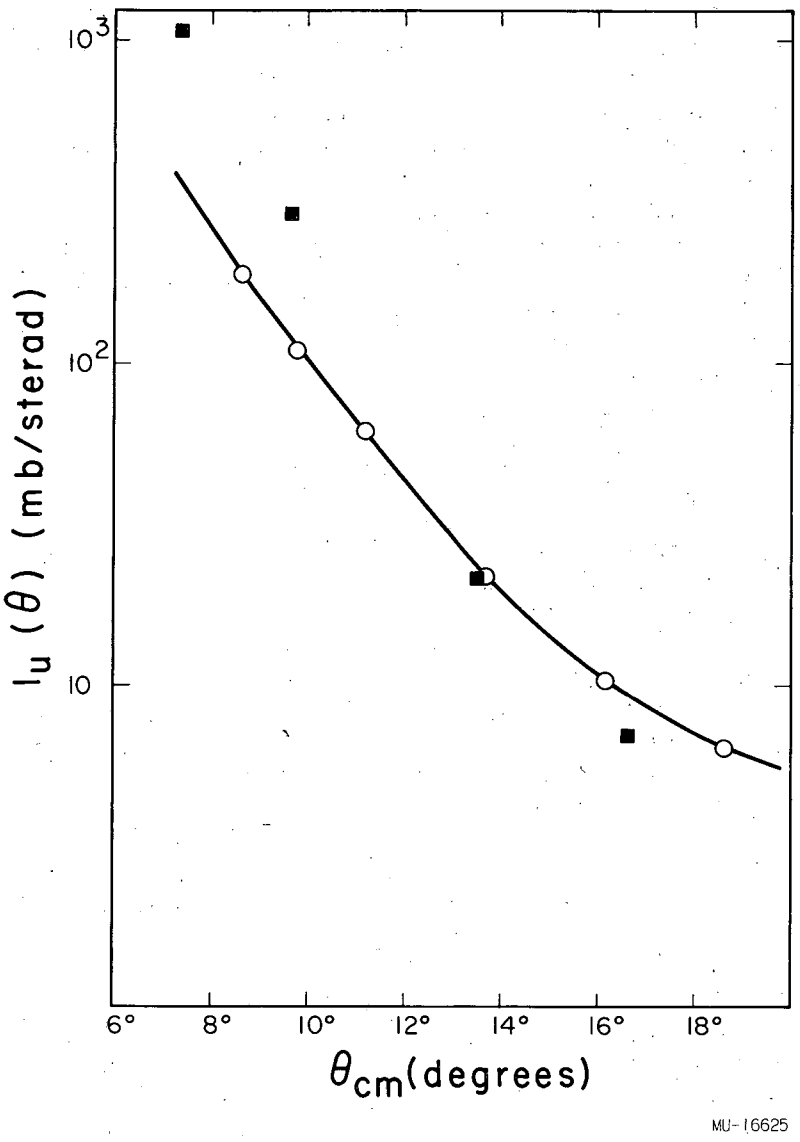

Fig. 4. Cross section for scattering of 410-Mev deuterons (unpolarized) by beryllium. Impulse-approximation calculations were made by assuming validity of Born approximation and charge independence and extracting nucleon-scattering amplitudes from 220-Mev proton-scattering data of Hafner at Rochester. Points indicated + represent predictions of impulse approximation from nucleon data (in Born approximation).

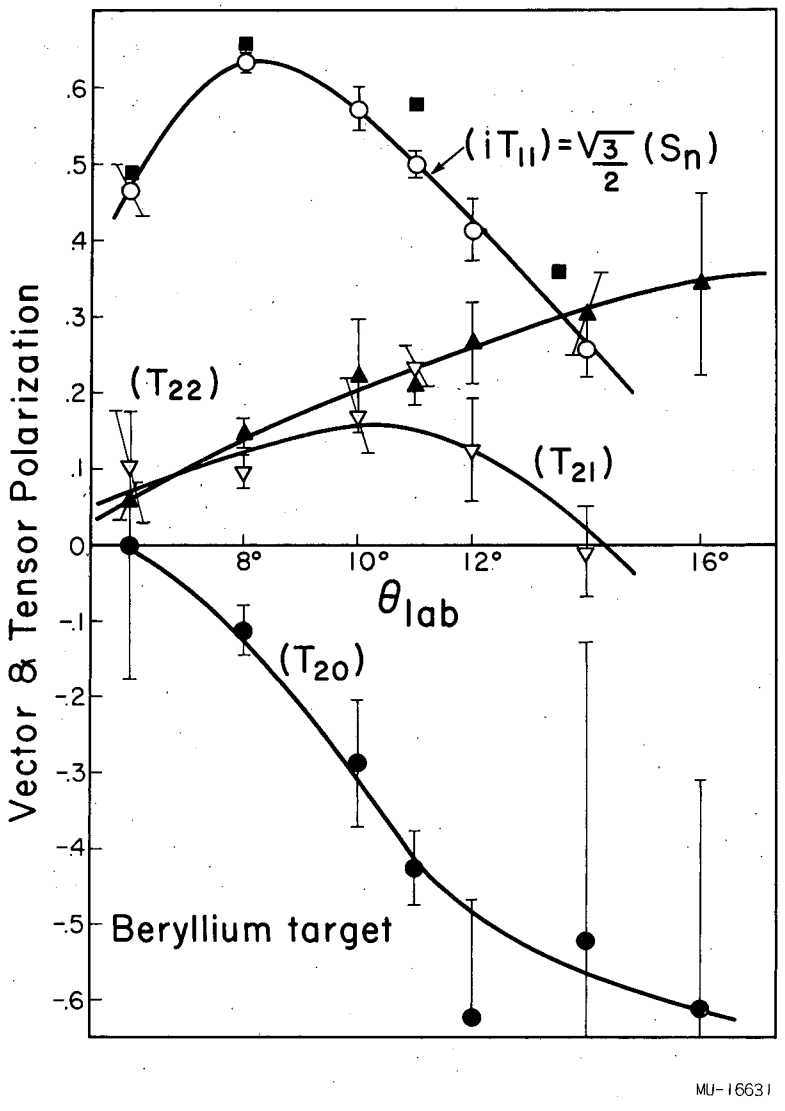

Fig. 5a. Vector and tensor components of polarization in scattering of deuterons by beryllium at 410 Mev. $\langle iT_{11} \rangle$ and $\langle T_{21} \rangle$ were separated by use of the two beams deflected differently in the cyclotron field. S_n is the component of spin normal to the scattering plane; other T's are second-rank tensor products of spin operators. (Errors are statistical.)

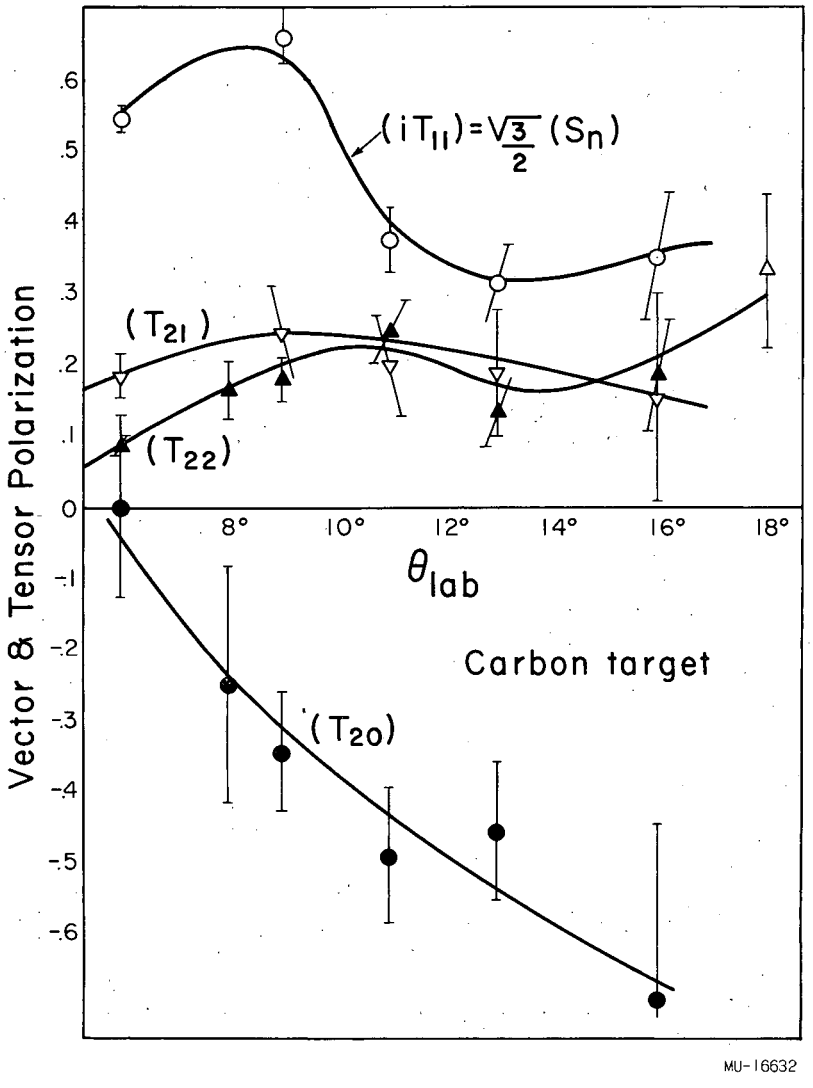

Fig. 5b. Vector and tensor components of polarization in scattering of deuterons by carbon at 422 Mev. $\langle iT_{11} \rangle$ and $\langle T_{21} \rangle$ were separated by use of the two beams deflected differently in the cyclotron field. S_n is the component of spin normal to the scattering plane; other T's are second-rank tensor products of spin operators. (Errors are statistical.)

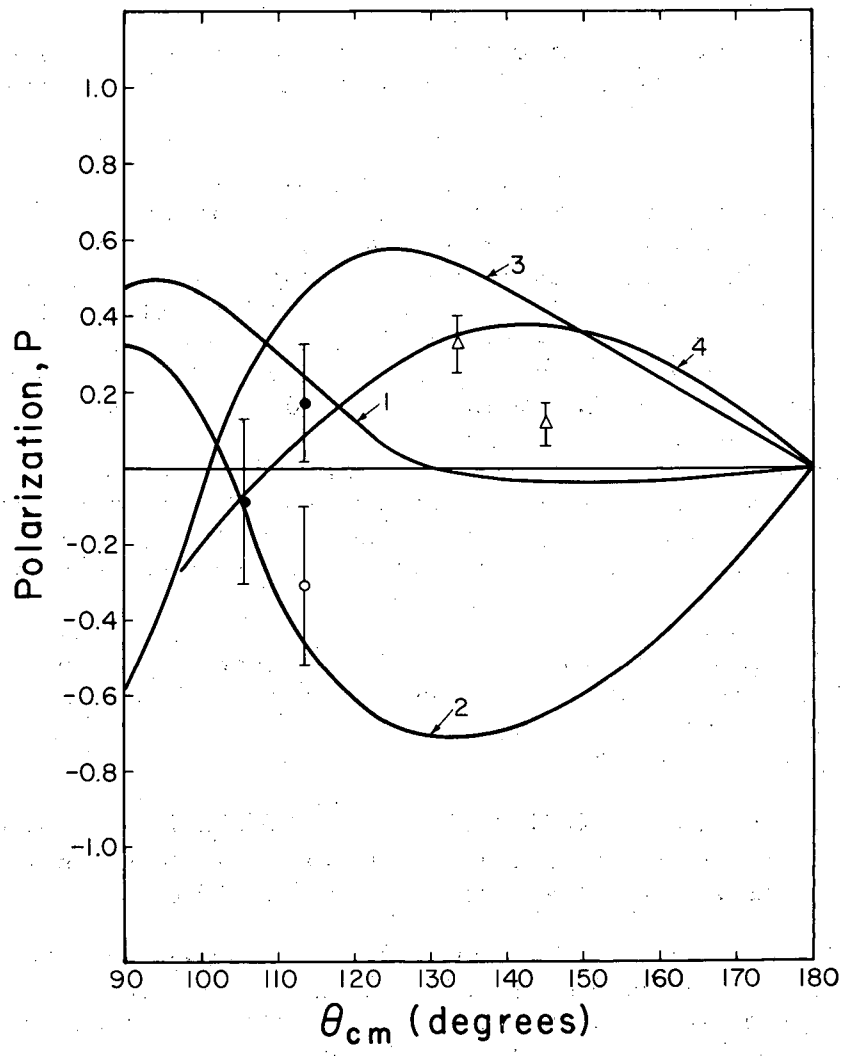

Fig. 6. Polarization of the recoil proton in π^+-p scattering at 310 Mev (preliminary results). $\theta_{c.m.}$ = scattering angle of π or proton (c.m.)
θ_2 = proton recoil angle (lab), O= θ_2 left, ●= θ_2 right with sign of e reversed, Δ=includes θ_2 left plus θ_2 right with sign of e reversed.

μ-MESON POLARIZATION

Gerad Harris, William Johnson, Juliett Lee,
Ernest Rogers, and Tom Ypsilantis

An exploratory experiment has been made on the determination of the sign of the polarization of μ^- mesons relative to their momentum in π^--meson decay.

A momentum-analyzed beam of 10-Mev π^- mesons was obtained by bombarding a copper target with the external proton beam of the 184-in. cyclotron. Negative μ mesons decaying at an angle such that they should be transversely polarized were observed in photographic emulsions. The observed intensity of the μ^--meson beam was sufficient to obtain the direction of polarization with reasonable statistics in 10 hours' exposure time. This is done by observing the asymmetry in large-angle Coulomb scattering in emulsion. Unfortunately, background was 100 times as great as allowable.

It appears, however, that the experiment can be done by bringing the μ-meson beam outside the physics cave, where background is only 1/1000 as great. A magnetic channel has been designed for this purpose which is expected to yield 1/10 as much μ-meson flux as we observed in the exploratory experiment.

Therefore, with this new system, we expect a good ratio of effect to background. The μ-meson flux is expected to be sufficient to complete the experiment in a reasonable time.

THE ANTIPROTON-NUCLEON ANNIHILATION PROCESS. II.

Owen Chamberlain, Gerson Goldhaber, Louis Jauneau,
Theodore Kalogeropoulos, Emilio Segrè, and Rein Silberberg

The analysis of pre-1958 antiproton exposures has been completed and submitted by us to the Physical Review for publication under the above title. In this paper we present the analysis of 221 antiproton stars, 95 of which occurred in flight. We find an average antiproton cross section of $(1.9 \pm 0.2)\ \sigma_0$, where $\sigma_0 = (1.2 \times 10^{-13} A^{1/3})^2$ cm^2, for the elements in emulsion, excluding hydrogen. The primary antiproton annihilation gives rise to 5.36 ± 0.3 pions on the average. Of these pions, 1.3 and 1.9 respectively interact with the nucleus for the cases of stars at rest and in flight. For stars at rest the energy available in the annihilation in complex nuclei is divided up amont the products as follows: charged pions, $48 \pm 6\%$; neutral particles (other than neutrons and K^0 mesons) $28 \pm 7\%$; K mesons $3 \pm 1.5\%$; and cascade nucleons and nuclear excitation $21 \pm 2\%$. For the stars in flight the corresponding percentages are: $45 \pm 7\%$, $22 \pm 7\%$, $3 \pm 1.5\%$ and $30 \pm 2\%$. To fit the average pion multiplicity, the interaction radius of the Fermi statistical model must be taken as $2.5\ \hbar/m_\pi c$. Other proposals to explain the large multiplicity are discussed. We deduce from the fraction of pions interacting in the same nucleus that the annihilation takes place at the outer fringes of the nucleus.

Segrè

EVALUATION OF NEW DATA IN STUDY OF ANTIPROTONS BY THE NUCLEAR EMULSION TECHNIQUE

Gerson Goldhaber, Wonyong Lee, Rein Silberberg, and Ted Stubbs

The scanning and measurement program on the antiproton stars from the January 1958 "doubly separated" exposure is in progress.

To date we have found 440 antiproton annihilation stars in Stack 88 (Ilford G.5 3X gelatine diluted emulsions) and 150 stars in Stack 89 (Ilford K.5 fine-grain emulsions). Measurements on these stars, designed to find differences between interactions in light and heavy elements, are in progress.

We are continuing our work[1] on the low-energy ($T\bar{p} \leq 230$ Mev) $\bar{p}$ - hydrogen scattering cross sections. We now find $\sigma = 73 \pm 15$ mb. on the basis of 26 events.[2] The angular distribution is strongly peaked forward; only three events have $\theta\bar{p}_{cm} > 90^{o}$.

We are also compiling further data[3] on the $\bar{p}$-nucleus elastic scattering reaction. It is hoped that, as these data become more precise, we shall be able to determine some of the parameters in the optical-model potential by these means. Comparisons with calculations by Fernbach and Glassgold are in progress.

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[1] Gerson Goldhaber, Theodore Kalogeropoulos, and Rein Silberberg, Antiproton-Hydrogen Scattering and Inelastic Scattering from Complex Nuclei, Phys. Rev. 110, 1474 (1958).

[2] This includes seven events by Ekspong et al. See report by O. Piccioni, CERN High Energy Conference, Geneva, 1958.

[3] Gerson Goldhaber and Jack Sandweiss, Elastic Scattering of Antiprotons from Complex Nuclei, Phys. Rev. 110, 1676 (1958).

Segrè

ANTINUCLEON EXPERIMENTS: PROPANE BUBBLE CHAMBER

Lewis Agnew, Louis Gilly, Richard Lander,
and Howard White

Analysis of the propane bubble chamber experiment in conjunction with the Powell group is proceeding. Basic description of this experiment was included in the preceding Semiannual Report. A complete double scan of the film was made and more than 500 antiprotons were detected. Of these, 487 are "clean" events which can yield a thorough analysis. The measuring of these events on the digitized microscope has recently been completed; fundamental quantities such as track length, particle direction, and particle momentum have been obtained on both the primary antiprotons and their annihilation products through IBM 650 programming. Elastic scattering results on carbon and hydrogen have been published.[1] Computations on the annihilation events are near completion, and a paper is being prepared for presentation at the Los Angeles meeting of the American Physical Society in December 1958. This paper reports on the annihilation events, giving cross sections for carbon and hydrogen (222 Mev to rest), charged-pion multiplicities and momentum distributions, and neutral-pion multiplicity as determined from more than 100 gamma-ray conversion events within the propane. Both the carbon and hydrogen annihilation cross sections show a rapid increase with decreasing energy. Their ratio seems to be approximately constant at a value of about seven. Strange-particle production occurs in at least 2% of the annihilations.

HODOSCOPE FOR BUBBLE CHAMBER TRACK IDENTIFICATION

Richard Lander, Herbert M. Steiner, Clyde Wiegand

We have in an advanced stage of construction a matrix of scintillation counters to place immediately in front of the beam-entrance window of a bubble chamber. The matrix consists of an array of 22 vertical scintillators about 1/4 in. wide, and 8 horizontal scintillators 1/4 in. high. This arrangement subdivides a 2-by-10-in. window area into 176 cells.

The hodoscope will be used in conjunction with electronic identification of the particles to be studied in the bubble chamber, for example, antiprotons or K mesons. The electronic identification signal will be put in coincidence with the signals from the hodoscope by employing a multichannel coincidence circuit designed by W. A. Wenzel (and applied as described by Coombes, Cork, Galbraith, Lambertson, and Wenzel, Antiproton-Proton Cross Sections at 133, 197, 265, and 333 Mev, UCRL-8279, June 1958.) We are presently planning to display the signals from the 30 counters on two sweeps of a four-beam oscilloscope. The spatial coordinates of the particle track as it enters the bubble chamber will then be determined by the signals that appear on the oscilloscope.

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[1] Agnew, Elioff, Fowler, Gilly, Lander, Oswald, Powell, Segrè, Steiner, White, Wiegand, and Ypsilantis, Phys. Rev. 110, 994 (1958); and Phys. Rev. 1, 27 (1958).

Segrè

ANTINUCLEON EXPERIMENTS: COUNTERS

Owen Chamberlain

Preparations have been completed for an antiproton run at the Bevatron, expected to start late in December (1958). The major effort will be to determine yields of antiprotons from proton-proton collisions. The yields from proton-carbon collisions will be a natural by-product, since targets of polyethylene and carbon will be used. The yields will probably be studied for a small range of angle of the outgoing antiprotons within about 15° of the forward direction, and for antiproton kinetic energies (in the laboratory system) between 0.5 and 1.0 Bev.

In the same experiment the antiprotons will be used to measure total and annihilation cross sections in deuterium and hydrogen. It is expected that negative-pion cross sections on hydrogen and deuterium can at the same time be measured in the energy range 1.0 to 1.7 Bev, using the large pion contamination of the secondary-particle beam.

(To some extent the whole group will be involved in this work, with Chamberlain, Elioff, Steiner, Wiegand, and Ypsilantis taking primary responsibility.)

BEAM-PROFILE INDICATOR

Horace G. Jackson, Dick A. Mack, and Clyde Wiegand

The prototype of an apparatus for displaying the intensity distribution in external charged-particle beams has been tested at the 184-inch cyclotron. The equipment is described in a report by Jackson, Mack, and Wiegand given at the 5th Annual Nat'l Meeting of the Professional Group of Nuclear Science of IRE, San Mateo, Calif. Nov. 6-7, 1958.

The sensitive element, a row of plastic scintillators each 1 cm by 1 cm, was placed in an external beam of π^{+} mesons. Figure 7 is an oscillogram taken (a) with the beam off, and (b) with the beam on. The detector was approximately at the focus of an 8-inch quadrupole. For comparison, Fig. 8 shows the distribution obtained by a single explorer counter moved across the beam, parallel to the sensitive element of the profile indicator. The flux of particles was approximately 400 cm^{-2} sec^{-1} at the peak of the curves.

In a constant beam at the cyclotron the display is a steady pattern except for statistical variations in the counting rates. At the Bevatron the amplitudes decay with a 6-sec time constant. Each Bevatron pulse renews the amplitudes in accordance with the number of particles through each element.

The time constants of the electronic circuits were designed primarily for Bevatron operation, where the counters will be gated on only during beam spill. The test at the cyclotron employed no gating or coincidence circuits, that is, the counters were sensitive at all times during the test.

The apparatus will need minor refinements for general use at the Bevatron.

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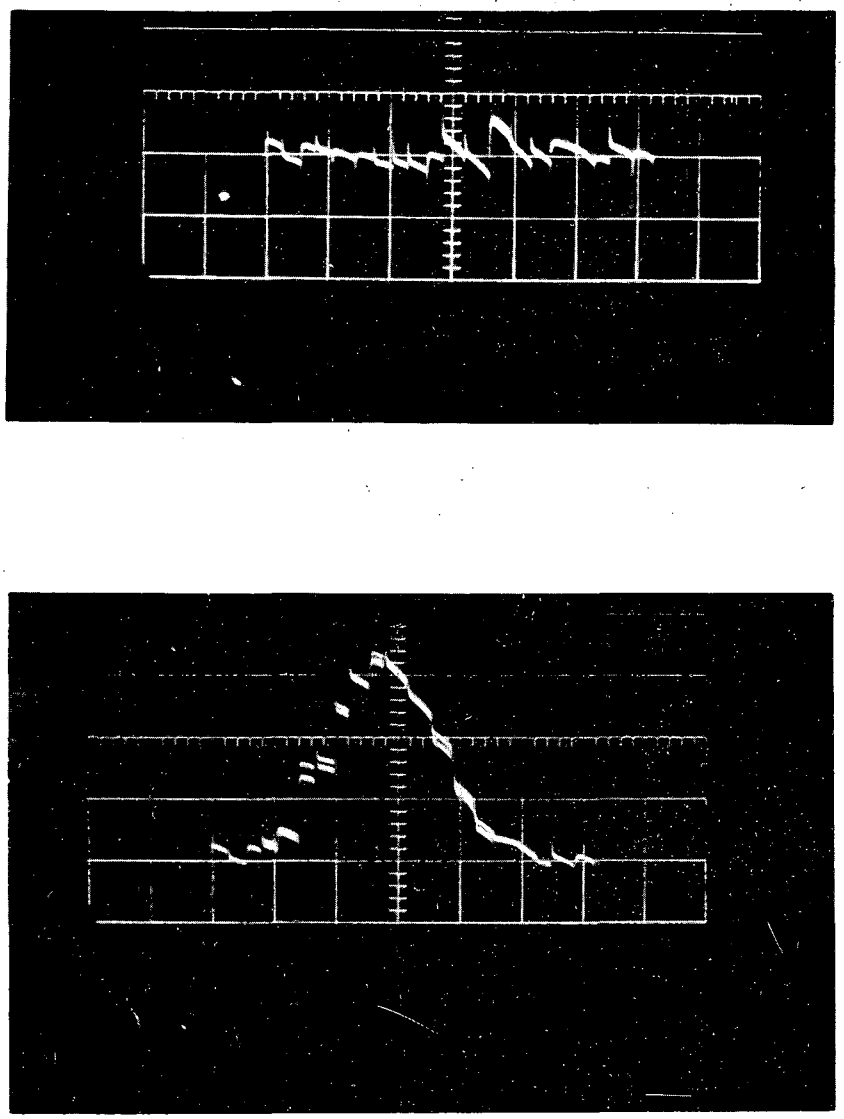

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Fig. 7. Horizontal beam-profile oscillograms: (a) beam off, (b) 400 particles/cm^2/sec at the maximum of the distribution. Each element along the abscissa corresponds to 1 cm.

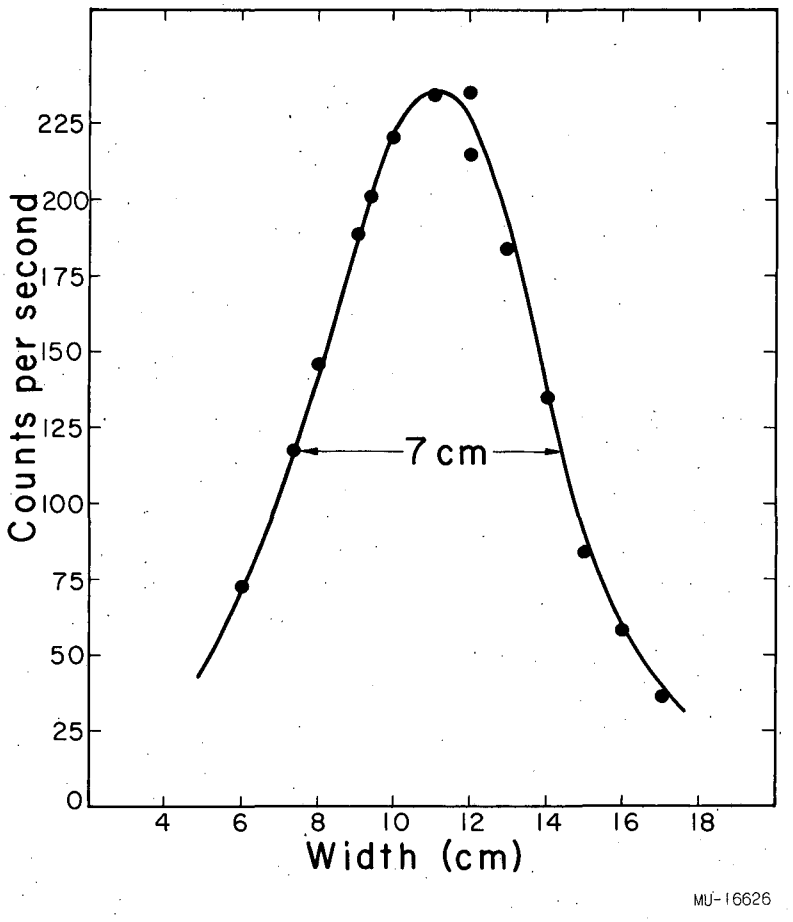

Fig. 8. Horizontal beam-intensity distribution obtained by moving a 0.6 × 0.6-cm counter across the beam. Counting rate at the maximum was 260 counts/sec.

ARC RESEARCH

Chester M. Van Atta in charge

HIGH-VACUUM AND ULTRA-LOW-TEMPERATURE REFRIGERATION

Hugh R. Smith

The major effort in this report period has been directed toward obtaining reliable performance from commercial mercury diffusion pumps. Considerable difficulty has been experienced throughout the laboratory in achieving satisfactory operation of pumps ranging in nominal size from 4-in. to 10-in. throat opening. Particular attention has been given to the 4-in. size, since this has been the most widely used pump. The following observations were made.

Currently produced 4-in. Hg pumps are built by using the corresponding oil-pump jet-nozzle spinnings. This in itself is not necessarily significant except that the same nozzle-throat clearances are used as for the oil pump. The effects of this were indicated by an experiment in which the cap of the top nozzle of a typical pump was removed and replaced with an adjustable nozzle cap by means of which the throat opening controlling the vapor flow was continuously variable. It was somewhat surprising to find that the maximum speed and base pressure of the pump were obtained with the top nozzle completely closed. This, of course, indicated either insufficient boiler heat and (or) too wide an opening of the two lower-stage nozzles.

Several other 4-in. pump jet assemblies were examined and measured. All of them had been assembled asymmetrically with respect to the pump centerline. In one extreme case the throat gap of the top nozzle was 3/32 in. on one side and only 0.010 in. on the other.

A new jet assembly was fabricated from machined parts so that cylindrical symmetry and precision fit could be achieved. (See Fig. 9). The bottom two nozzle openings were constructed so that they could be adjusted by shimming. The top nozzle was made continuously adjustable by a lead screw operable through a shaft seal. The pump-operating parameters that were varied in the test were the boiler temperature, the condensing-surface temperature, and the jet clearances on all three jets.

In the first series of tests the nozzle clearances on the bottom two jets were adjusted to correspond to the standard dimensions of commercial pumps. Under these conditions optimum performance was obtained with the top nozzle completely closed off. In the next series of tests the bottom two nozzle openings were arbitrarily set at half their former value. Under these conditions some improvement in performance was obtained with the top nozzle opened very slightly. In the next test the bottom jet was left unaltered and the middle jet opening was cut down to about 2/3 of its former value, and a very obvious optimum opening became apparent for the top jet. Satisfactory operation was obtained under these conditons, i.e., the pump

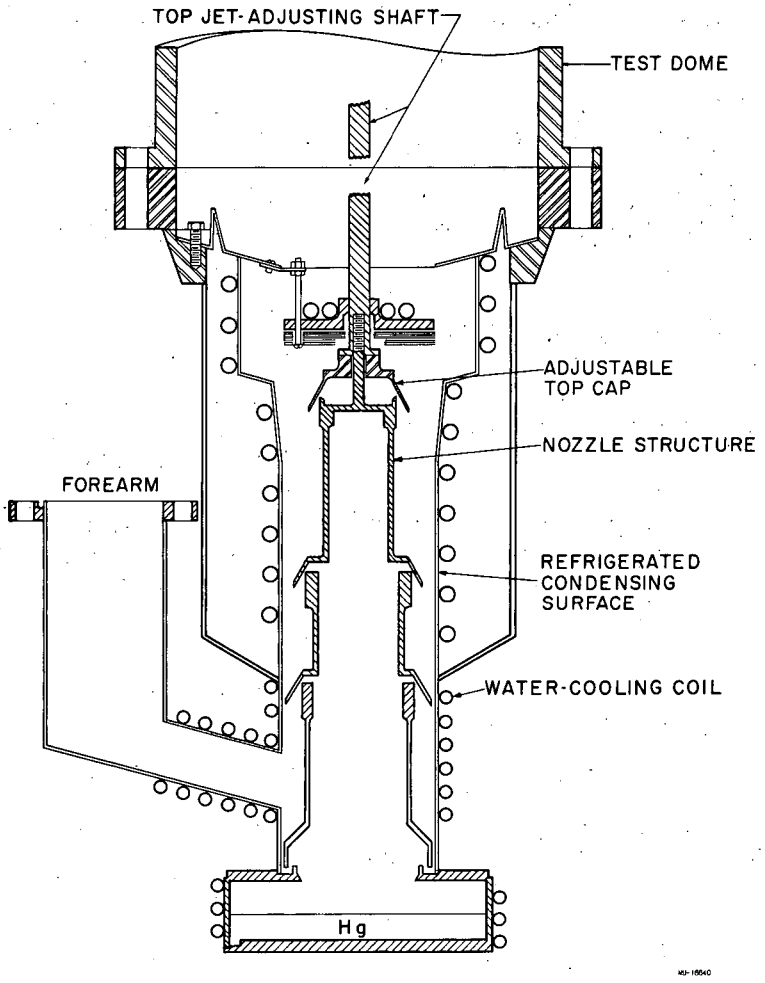

Fig. 9. Jet assembly for ultrahigh-vacuum pump.

achieved a pressure in the test dome of less than 10^{-7} mm Hg. No further tests could be made since the pump was needed as a piece of operating equipment.

It is realized that it would be entirely too fortuitous to expect that an optimum operating condition had been achieved with such a limited series of arbitrary adjustments. Several obvious conclusions can be reached, however.

(a) Nozzle-opening clearances in mercury diffusion pumps are much more critical than in oil pumps. The optimum performance in the pump tested was obtained with a throat opening which could not be varied more than ± 0.002 inch without serious fall-off of performance. As indicated earlier, commercial pumps examined do not come anywhere near such precision in their construction.

(b) The operating conditions for mercury pumps are also much more critical than for oil pumps. Considerable decrease in pumping speed was noted when the barrel condensing surfaces were not held between -30 and -37°F. Also the lower-barrel cooling-water coil had to be run hot (output water temperature between 90 and 95°F) to achieve optimum performance.

Work is continuing on further improvement of the operation of mercury pumps in all sizes, with particular emphasis toward achieving reliable operation over a broader range of operating conditions.

ACCELERATOR OPERATION AND DEVELOPMENT

BEVATRON

Edward J. Lofgren in charge

Reports for May through July 1958 and August through October 1958 are to be issued separately as "Bevatron Operation and Development, XVIII," UCRL-8563 and "...XIX," UCRL-8564.

184-INCH CYCLOTRON

Robert L. Thornton in charge

Reported by James T. Vale

The 184-inch cyclotron is still in a period of debugging, thus innage time was only 81.6% during the last 6 months. The largest outage time was caused by a shutdown for the primary purpose of drilling a hole in the meson cave, 150 feet deep and 24 inches in diameter, to be used in an experiment involving time of flight of particles. At the same time, two of the generators that power the main cyclotron magnet were sent out to be overhauled. They were cleaned and the insulation was repainted to bring the leakage resistance back up to a safer value. The rotating parts then had to be rebalanced. It was felt necessary to overhaul the machines because they had been running for years and their insulation resistance had lowered--not to a danger point, but to a point at which it needed improvement.

Considerable trouble had been encountered with these generators in the form of commutator sparking also. At the time of the insulation improvement, the commutators of both machines were reconditioned and new brushes installed. However, commutator sparking proved to be a problem after the generators were put back in service, and considerable time had to be devoted to this problem. The sparking became dangerously bad during one day of exceptionally low humidity, and after that could not be improved in spite of careful adjustment and maintenance.

The problem was solved by turning the commutator in place and then using live steam (blowing on the commutator) for lubrication for a period of about a week until the proper oxide film had formed. The generator has been running about two months now with very little sparking. A new brush-holder design is now under way, to put in about 10% more brush surface. This is possible because the commutator is somewhat longer than the present brush holders. In addition, increased brush surface will be obtained by placing the brushes closer together.

In June, the external beam dropped essentially to zero. It was found possible to restore the external beam to its normal value by shunting off about 40 amp of the current supply to the lower main coils. Investigation of this problem showed that the lowest section had approximately 60% of the resistance that it should have. All the other sections were normal. The faulty layer had good insulation to ground and to its adjacent section; the indication is that parts of the turns have been shorted only to each other. As long as the shorted turns remain static, there seems to be no danger in running the magnet this way. Recently it has been noticed that the voltage across the faulty section varies abruptly while the voltage across the adjacent section remains essentially constant. This indicates that the short must be arcing minutely, and a program is under way to try to locate the short and then decide what can be done. It must be pointed out that getting to the coils is extremely difficult, and repair work on them is more difficult by at least an order of magnitude. It may be possible to remove the faulty coil from the circuit and, by reconnecting the coils--with perhaps increased current through the remaining coils--to enable the cyclotron to operate. Increased current will present a problem, since the generators are over-loaded now, and any additional load will make matters worse.

The cyclotron was used by the three main groups during the last six months as follows:

Physics	68.3%
Chemistry	3.1
Medical	10.2
Total innage	81.6%

60-INCH CYCLOTRON

W. B. Jones in charge

DEVELOPMENT

Ion-Source Adjustment Mechanism

Roy F. Burton

The ion-source adjustment[1] has been in operation for the past six months. It was designed by Charles A. Corum, and built in the UCRL machine shops. Final assembly and testing were done at Crocker Laboratory, and installation on the 60-inch cyclotron took approximately 8 hours.

Figure 10 shows the component parts of the assembly. The various mounting plates, the gate housing, and the slide plates are mounted to the 60-inch cyclotron vacuum tank. The seal plate and in-out worm drive are removed with the ion source. The seal plate rests on a locating pad, and is held in position by toggles which can be disconnected quickly.

Linear potentiometers have been mounted on this assembly and are connected to meters on the 60-inch-cyclotron control desk. These potentiometers measure the position of the ion source, and a reliable reproduction of positions is obtained.

Water-Cooled Beam-Defining Probe, Mark II

This device, designed for use on the 60-inch cyclotron, and often referred to as a "beam clipper," is for collimating the external beam. It operates through the standard probe port, which is situated between the dees. See Fig. 11.

An outer flag, which operates through a support tube, is held in position by guide tubes attached to an inner flag. These tubes are fastened to the support-tube head by setscrews, and are sealed by "O" rings at the ends. Spur drives control the various movements. The support-tube inner-flag drive positions the whole assembly with respect to the beam, while the outer-flag drive adjusts the beam-collimating gap. At present, a 7/16 inch maximum is used, but up to 1.5 inches can be obtained by varying the length and engagement of the guide tubes.

Remote Operation of Vaccum Valve

The roughing valve in the line connecting the house vacuum to the target chamber has always been manually operated. Heavy target assemblies have required two operators; i.e., one to hold the target, and one to operate the valve. In addition, one of the operators had to remain at or return to this high-radiation area to close the valve when the target gate was opened.

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[1] Physics Division Quarterly Report, UCRL-2920, March 1955, pp. 38 and 41.

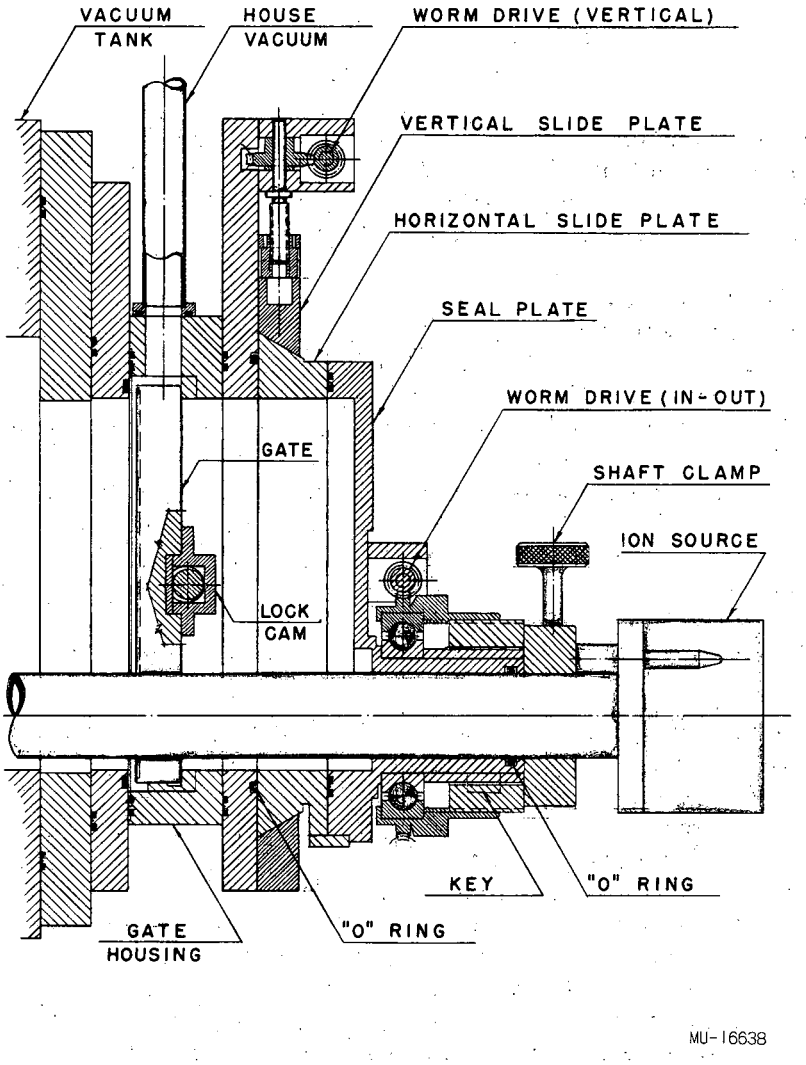

Fig. 10. Ion-source adjustment.

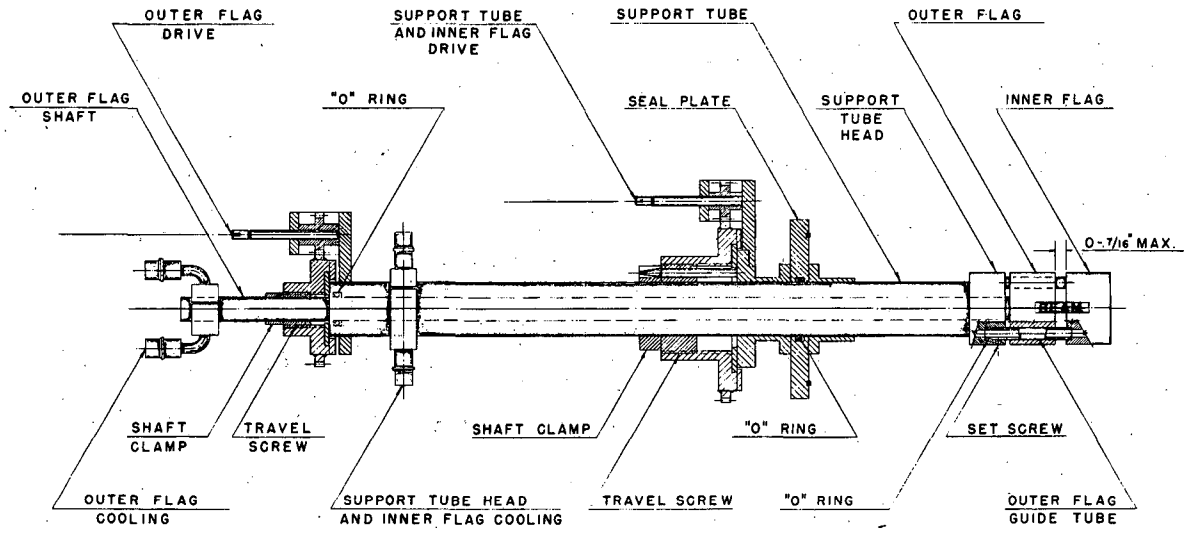

Fig. 11. Water-cooled beam-defining probe, Mark II.

The valve is a 90° ball type, which has proven very satisfactory. A small nonmagnetic short-stroke air cylinder was built and installed alongside the valve, and the piston rod was linked to the valve handle. A four-way air solenoid operates this cylinder. The solenoid can be operated by a button near the target chamber, which leaves both the operator's hands free for target handling. In addition, a push button located in a radiation-free area permits remote operation of the valve. As soon as the button is released, the switch returns to neutral so that the vacuum valve can be manually operated.

Integrating Electrometer

Kenneth D. Jenkins

Around every accelerator, where widely varied bombardments and conditions are used in the day-to-day operation, a direct-reading wide-range current integrator (10^{-4} to 10^{-12} amp) is required, offering simplicity in making range changes, having the ability to take any overload, and needing only ordinary handling.

The integrating electrometer herein described is actually two circuits in one: a feedback-current electrometer, followed by a Miller integrator. The entire electrometer is housed in a standard 5-1/4-inch relay-rack panel.

The current amplifier amplifies both positive and negative currents in seven ranges of 10^{-4} to 10^{-10} ampere. Either a continuous current, or pulses as slow as 10 pulses per second with a duty time of 0.1%, can be amplified. A 'scope output is available to permit observation of the shape of the beam pulses.

The shunt resistance on the input can be checked to determine the probable error in metering the target.

The integrator integrates the output of the current amplifier in units of milliampere-hours times the particular current-amplifier range being used (10^{-4} to 10^{-10}).

The integrator is self-discharging; it has a four-digit register, thus giving a range of 3.6 to 3.6×10^{-10} coulomb for full-scale readings. The standard calibration current injected into the current amplifier also allows calibration of the integrator by means of an internal timer.

The self-discharge ("dump") is accurate to within 0.5%. The meters used give only 2% of full-scale reading, however; thus it takes five dumps to realize the full over-all accuracy of the machine.

To eliminate errors due to shunt impedance on the input, the electrometer holds the input voltage to ± 3 mv for 8 hours. The grid leakage current is less than 10^{-13} amp within minutes after a serious overload has been accidentally put on the input.

The circuit consists of precision input resistors, a polystyrene capacitor, and associated selector switches; two feedback-electrometer amplifiers; and a trigger amplifier for discharging the capacitor and operating the register--all operated from a single stable regulated power supply.

The power-supply regulator includes both a VR tube that supplies regulated 150 volts positive and that supplies regulated 150 volts negative; a second regulator supplies a very stable 10-ma filament current for the two electrometer tubes. The reference voltage for the regulator is a third electrometer tube with a 45-volt battery connected from the filament bleeder to the grid of the reference-electrometer tube. Any change in the three electrometer tubes shifts the reference voltage to re-establish the previous conditions.

The feedback electrometers have no special circuitry and use a CK5886 electrometer tube, a 6AU6 amplifier, and a 12AU7 output driver. The output voltage is -35 to +100 volts with a 1-ma load. The over-all gain is about 50,000.

The trigger amplifier is a one-shot multivibrator which operates a high-speed shorting relay. The relay shorts out the charge built up on the integrating capacitor and sends a pulse charge to the register.

The input section, Fig. 12, shows the relation of the switching circuits. The range is selected by the feedback resistor R1A through R1H. The range switch has three adjacent resistors connected at all times; thus the selector switch can select which of the three resistors is to be used. The meter selector switch has 8 positions (0.05, 0.1, 0.25, 0.5, 1, 2.5, 0, calibrate).

On the zero position, the first of the input resistors is connected to common, and the third resistor is connected to the feedback; thus any small voltage at the input terminal is amplified X 100. Then with the current meter set at 1 volt, a 10-millivolt variation of the input gives a full-scale deflection of the meter. When on zero, the standard cell button will switch in the standard cell, the voltage across R12, R13 can be adjusted to 1.019 volts.

On calibrate, a 0.9-volt signal is put on the first imput resistor, and the feedback is connected to the second resistor; thus the feedback voltage is 9 volts. A 9-volt signal on R8 makes the integrating capacitor C2 charge to 50 volts in 4 seconds. A 15-rpm clock rotates a dial behind the interpolator meter face. The clock dial circumference is the same length as the interpolate meter scale. With the 9-volt signal in, the integrator charges and discharges once every 4 seconds; thus the interpolate meter pointer moves in synchronism with the clock dial. After several cycles, the two will be out of synchronisation if there is any error.

On the 2.5, 1.0, 0.5 positions, only the beam meter changes scale to aid in reading the current. On the 0.25, 0.1, 0.05 positions, however, the feedback is changed to the third input resistor, which changes the scale of the electrometer by ten, but resistor R9, which is ten times as large as R8, maintains the integrator at the same charging rate.

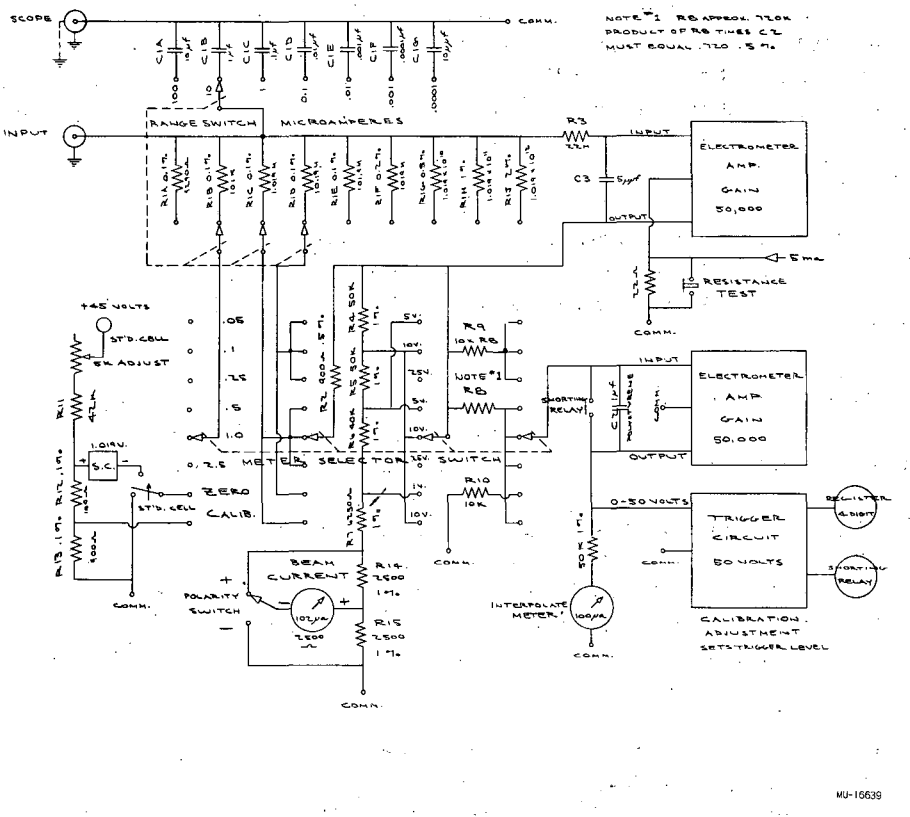

Fig. 12. Integrating electrometer.

The input resistors R1A through R1H are decade increments of one another when the value of R2 is added in. R2 is used to compensate for the internal impedance of the calibrate circuit. The input capacitors C1A through C1G absorb any pulses on the input, and the filter R3, C3 keeps the pulses out of the electrometer. The unit is ground at the scope output plug. Either a shorted plug or a small resistor must be used to develop a 'scope voltage.

OPERATION

Experiments at the Cyclotron

Peter F. McWalters

Helium-3 was accelerated by the 60-inch cyclotron for Dr. Samuel Markowitz. Dr. Markowitz furnished a 2-liter bottle of helium-3 gas of 4% enrichment.

We felt that the acceleration of He_3^{2+} could best be accomplished by using our normal operating radio-frequency of 12 Mc, and by reducing the magnetic field from the normal operating point of 16,000 gauss at the center to a magnetic field whose central field is 12,000 gauss. Unfortunately, such a shift in magnetic field intensity drastically changes the shape of that field (see Fig. 13). At 12,000 gauss, the magnetic field is increasing radially at the 18-inch radius, consequently the beam is defocused or "blown up" to the extent that no particles can be detected beyond that point.

The maximum beam intensity measured was 3 μa at the 17.5-inch radius, which corresponds to an energy of 18 Mev. A copper target was bombarded at this radius, and the 2.5-min gallium (Ga^{64}) was detected. A stack of 1-mil beryllium foils was bombarded, and 20-min carbon-11 activity was found in the last foil of the stack; this would not be possible with He_4 ions.

We believe that the gas system had leaked, and that a much larger beam would have been obtained if a higher enrichment or a more pure gas source had been available.

In order to carry out short-half-life experiments, Roy Burton designed an air-operated plunger, which is used in conjunction with a mechanical beam shutter,[1] so that the beam is available at the target only when the target is in place. This apparatus allows the target to be alternately exposed to the beam for 2 seconds and then pulled back to a counter for 10 seconds with minimum background radiation. Using this, Dr. Stewart Bloom irradiated beryllium-9 with alpha particles to obtain lithium-8 by $\alpha, \alpha p$ reaction. The half life was measured as 0.80 ± 0.02 second. The curve of cross section vs energy was also determined, and will be reported by Dr. Bloom.

[1] K. D. Jenkins and W. B. Jones, Rev. Sci. Instr. 29, 898 (1958).

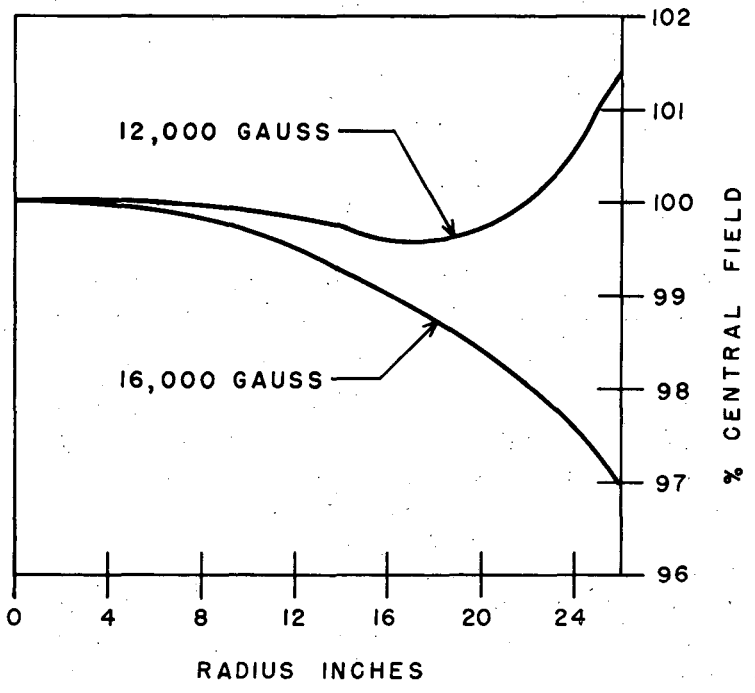

Fig. 13. Radial magnetic field.

A chemistry group under Dr. Stanley Thompson[2] irradiated einsteinium-253 with alpha particles of approximately 5-μa beam intensity (a beam density of approximately 100 $\mu a/cm^2$), using the deflector-channel probe.[3] This resulted in the identification of a new isotope of mendelevium (element 101), with mass number 255 and a half life of approximately 0.5 hour. Also, a revised half life of 1.5 hours was measured for the electron-capture decay of mendelevium-256.

Effect of 60-Inch Cyclotron Operations on Low-Level Counting Experiments

Robert J. C. Cox

Lately there has been a need to work closer and closer to the natural background of radioactivity, and the 60-inch cyclotron influences the level of this background.

This problem first arose in 1955, when the Bio-Organic Group at Donner Laboratory began using their automatic G-M counter over week ends. Since this week-end work was often at very low levels of activity, and the 60-inch cyclotron was accelerating large deuteron beams, the experiments at Donner Laboratory were frequently inconclusive because of shifting levels of background (the background varied with target changes and beam levels). At that time, it was impossible to subtract a changing and unknown background.

This need to detect and follow changes in background brought about the building of a continuously recording 10-liter ionization chamber. The chamber showed that there was an increase of as much as 50% in background during the week, and on occasional week ends the background might be doubled.

In addition to these phenomena, there occurred rapid and intense fluctuations which also doubled background. Additionally, some short "spikes" were observed that were five times as high as background, but lasted for such a short time that they were no problem for Donner Laboratory work (see Fig. 14).

Close comparison of Donner Laboratory records and 60-inch cyclotron log books for a period of 6 months revealed that the small weekly variations (maximum increase of 50% over background) correlated with the alpha-particle beam. These changes corresponded to beam levels, and were essentially independent of the target material bombarded. Week-end operations with larger background changes followed the deuteron bombardments, and those pesky rapid week-day shifts in background level appeared to be the result of biological bombardments for the Navy with proton beams on Be. The "spikes" are believed to be a phenomenon of nature.

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[2] Phillips, Gatti, Discovery of a New Mendelevium Isotope, Phys. Rev. Lett. 1, 215 (1958).

[3] Rossi, Corum, and Jones, Deflector Channel Probe, in Physics Division Quarterly Report, UCRL-3410, May, 1956, p. 32.

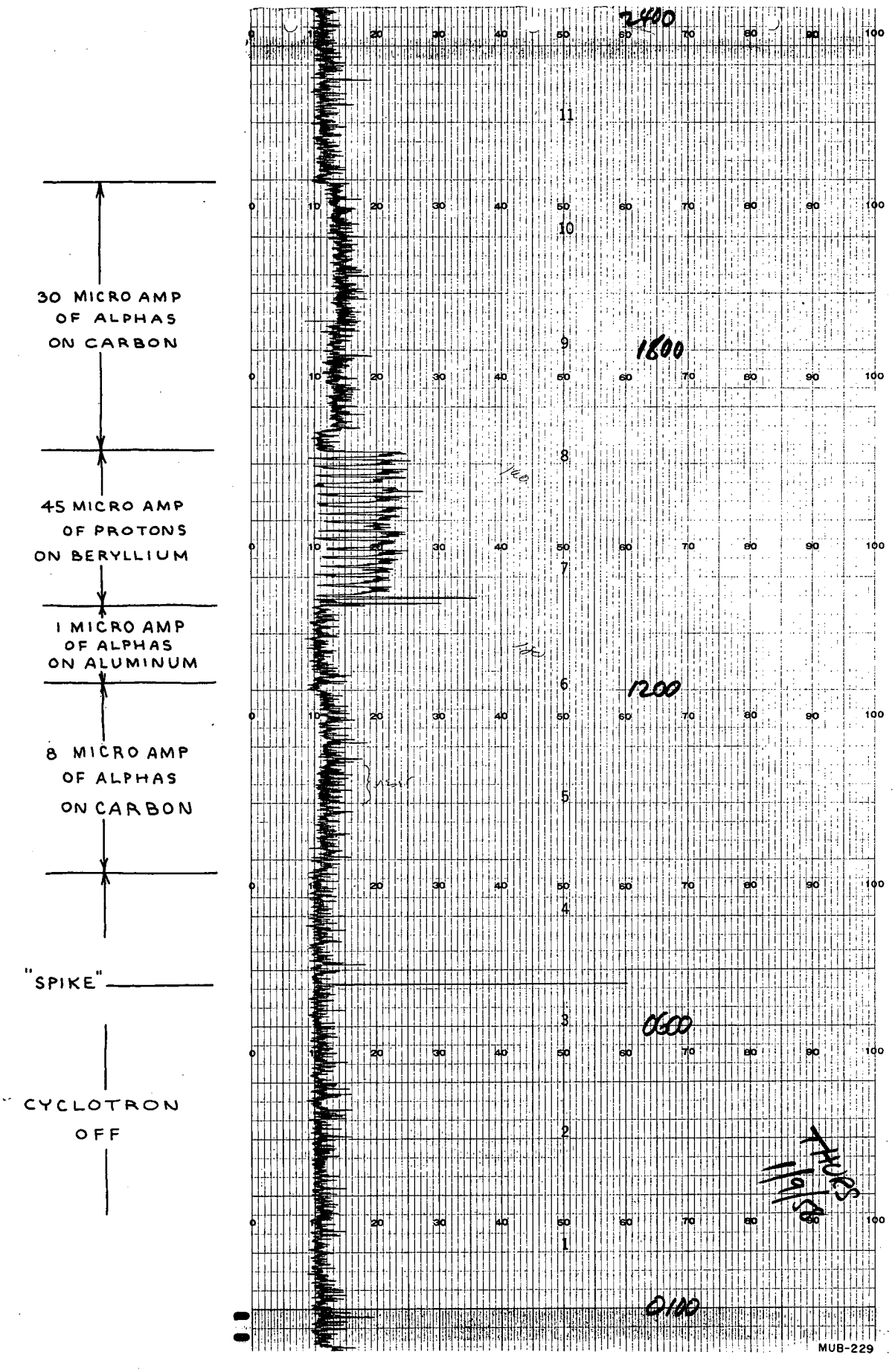

Fig. 14. Graph from continuously recording ionization chamber.

Although less than 10% of the bombardments were with deuterons, it seems to follow that, microampere for microampere (Fig. 15), the deuteron beam causes an increase of approximately 5 times background, whereas the change caused by the alpha-particle bombardments was less than twice background. There are even poorer data for proton bombardments, but the data indicate that the proton beam is slightly more effective in raising background than the alpha-particle beam. A summary of all bombardments made at the target port during the 6-month survey showed that only 18 μa of deuterons doubled the background, whereas 72 μa of protons, or 94 μa of alpha particles was needed to cause the same effect at Donner Laboratory.

Some of the large changes in background were due to the use of the beam outside the water shielding. This beam is low in intensity (usually less than 1 μa), but because it was outside the water shielding, its effect was much larger. We have installed 12-inch-thick "heavy" concrete doors to shield this area off, as well as a 12-inch concrete overhead to kill the "sky shine." These measures appear to have reduced the change in background at Donner Laboratory to approximately one-half the former value.

To further assist the researchers at Donner, the 60-inch cyclotron group is providing advance notice of all bombardments, so that the low-level work (approximately 20% of the Donner Laboratory work) may be scheduled during the "quiet" periods.

To summarize: The 60-inch cyclotron was found to have caused an increase of as much as 5 times the normal background at Donner Laboratory. By scheduling and by shielding, 60-inch cyclotron and Donner Laboratory personnel achieved a workable solution of the problem.

Summary of Usage

Summary of usage as prepared by Peter McWalters for this 6-month period:

Alpha bombardments	1,650.5 hr
Proton bombardments	207.4 hr
Deuteron bombardments	200.9 hr
Helium-3 bombardments	16.7 hr
Experimental bombardments	131.7 hr
Operational total	2,207.2 hr
Outage	250.7 hr
Available time	2,457.9 hr
Shutdown	1,894.1 hr
Holidays	64.0 hr
	4,416.0 hr

An operating efficiency of 89.8% was maintained throughout this 6-month period.

60-Inch Cyclotron

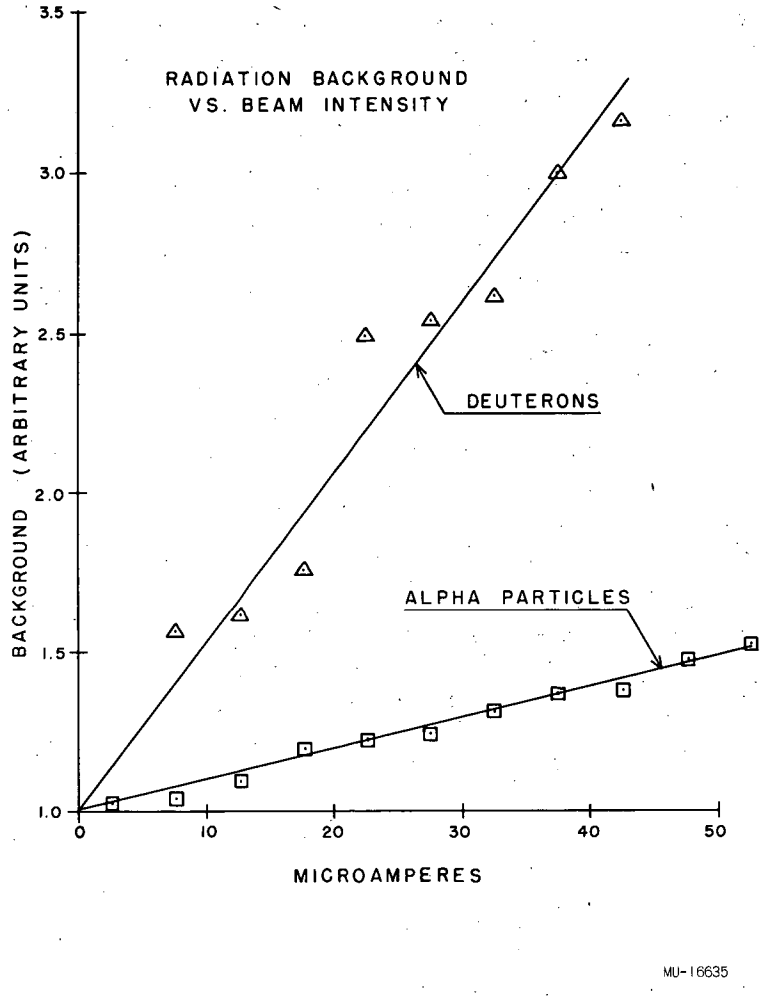

Fig. 15. Radiation background vs beam intensity.

HEAVY-ION LINEAR ACCELERATOR

Chester M. Van Atta in charge

Reported by Edward L. Hubbard

OPERATION

Time that the Hilac operating crew was on duty was increased as follows:

Prior to July: 16 hr/day, 5 days/wk.

July, Aug., and first half Sept: 16 hr/day, 5 days/wk + 8 hr on Saturday

Second half Sept. and Oct: 16 hr/day, 7 days/week.

Of the crew time, 74% was used by experimenters and the remainder for troubles, maintenance, installation and development. The experimenters' time was distributed as follows:

Chemistry		68%
Heavy-element production	24%	
Coulomb excitation	19%	
Other	25%	
Physics		21%
Medical Physics		11%

The ions listed below were accelerated for the first time:

He^3	0.01	- particle-μa av. beam
He^4	0.5	"
B^{10}	0.003	"
B^{11}	0.02	"
F^{19}	0.01	"
Ne^{22}	0.01	"

DEVELOPMENT

Improvements to the machine and additional facilities completed were:

1. Servo to keep the prestripper cavity timed to the frequency of the poststripper.

2. Servo to hold the rf gradients in the cavities constant during line-voltage fluctuations.

3. Main amplifier coupling loops in prestripper cavity to facilitate switching to 1-Mev/nucleon beam energy.

4. Counting area.

5. Facilities to test and develop ion sources.

SYNCHROTRON

Rudin M. Johnson in charge

OPERATION

The synchrotron has been used primarily for physics research experiments during this period. The beam intensity was run as high as 2×10^9 electrons per pulse for Knapp's experiment in June, and had to be reduced by a factor of 1000 for Cence's experiment in July and August.

The synchrotron was torn down for two weeks in mid-June to replace the standard quartz-target segment of vacuum doughnut with an epon plastic segment, which is provided with two 0.007-inch aluminum windows 1 in. wide by 8 in. and 6 in. long, respectively. This epon plastic vacuum segment was developed and fabricated by the synchrotron crew and accelerator technician. This special thin-window target segment was necessary to reduce scattering of the electrons and gamma rays coming from the synchrotron target through the vacuum chamber walls into Cence's monoenergetic gamma-ray experiment. Cence's experiment also required a 0.001-in.-thick platinum target instead of the standard 0.020-in.-thick Pt target.

A number of owl shifts were run during the experiments with the 4-inch deuterium bubble chamber. Operators for these extra shifts were provided mostly by synchrotron graduate students, with the regular crew filling in where necessary.

The electron linear accelerator was used by Dr. Newton for bombarding Mylar and other plastics films in air, helium, and methanol atmospheres, using the electron sweep magnet. Dr. Lemmon ran choline chloride samples for free-radical studies.

Jean Futrell ran a polymerization experiment on ethylene dichloride, using a special sealed flask. Dr. Kenney ran experiments on x-ray intensity versus angle for information desired by Dr. Libby of the Atomic Energy Commission.

Graeme Welch ran penumbra measurements of a high-intensity x-ray beam (approximately 4×10^4 r/hr measured) through a 4-mm collimator in preparation for possible future irradiation of mice.

The United Testing Laboratory of Monterey Park, California, ran tests on special missile components by microwave radiation from our high-power klystron.

DEVELOPMENT

Synchrotron developments during this period include the epon plastic vacuum segment mentioned above. A new injector-gun mount and positioning system was installed which reduced the high-voltage sparking around the injector. Studies were started on measuring the beam dynamics in the machine at all times during the acceleration cycle.

The frequency and amplitude of the betatron oscillations, the magnetic-focusing factor "n," and the necessary beam aperture (horizontal and vertical), are to be measured. Apparatus for these measurements is near completion.

Considerable progress has been made in cold-test designs of a microwave-cavity injector gun which will eliminate the insulator-breakdown problem in present gun designs. A sintered nickel oxide cathode is also being tested which will be used in present guns and future microwave-cavity guns.

The driver magnetron was stabilized to eliminate the 60-cycle frequency modulation which appeared as energy variations at high pulse rates.