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UNIVERSITY OF CALIFORNIA

Radiation Laboratory

PHYSICS DIVISION QUARTERLY REPORT

May, June, July 1957

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PHYSICS DIVISION QUARTERLY REPORT

May, June, July 1957

August 20, 1957

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*Preceding Quarterly Reports: UCRL-3782, UCRL-3689

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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 used during this quarter in a continuation of the neutron-spectra experiments being run for Dr. Moyer's research group. A series of short runs using 90° prism illumination was made as test runs to obtain design information pertaining to the proposed 15-inch chamber illumination system. The fast recompression system installed earlier in the year has proven entirely satisfactory.

10-Inch Chamber

Early in June the 10-inch chamber was installed in the northwest area of the Bevatron for continuation of the experiment (interaction of 1.1-Bev/c π^- in hydrogen, strange-particle production) that was interrupted by the Bevatron shutdown in February. A complete concrete shielding house was assembled around the chamber for this run. The shielding has essentially eliminated the background tracks of Compton electrons and electron pairs, which were so numerous in pictures taken in previous runs without shielding.

The running has been on a "compatible" basis, with the bubble chamber target taking about 5% to 10% of the Bevatron beam, the remainder being delivered to other experimental setups.

Running on the current experiment began on June 12 and has continued on a 5-day-per-week, two-shift basis throughout the rest of this quarter. Up to July 31, 93,000 pictures had been taken. The present run will continue until at least September 30 and possibly beyond that date.

15-Inch Chamber

In order to staff the 10-inch run currently in progress, it has been necessary to further delay the completion of the 15-inch chamber. During this quarter the vacuum system has been assembled and tested both for vacuum and internal pressure capability. The chamber was cooled to liquid nitrogen temperature and tested to the design pressure of 250 psig with a dummy window. The expansion system design was reworked, and an acceptable design evolved, based on fast acting valves manufactured by the Grove Regulator Co. Assembly of the chamber into the vacuum system and the necessary plumbing work are proceeding as rapidly as manpower permits.

Considerable design and test work (using the 4-inch chamber) went into the problems associated with the retrodirective illumination system. A satisfactory design has been completed and the work orders for the parts have been released to the shop.

The first hydrogen operation of this chamber is scheduled to take place early in November and, barring unforeseen difficulties, the chamber will be in use at the Bevatron in December.

72-Inch Chamber

Fabrication work is proceeding well. The magnet assembly has been completed and the vacuum vessel is now installed in the magnet. Magnetic measurements will commence early in August. It was decided to regrind and polish the Jena window to improve the flatness. A contract for the work was let and the job successfully completed. The stainless steel chamber casting was made and the chamber received from the supplier. The quality of the casting was in all respects better than our specifications. Final machining of the casting is now in progress. The design of the liquid hydrogen temperature shield is complete, and fabrication is in progress.

A final decision has been made on the film-to-chamber demagnification of the photographic image (15:1), and design of the camera system and illumination system can proceed.

The high-pressure hydrogen-storage cylinders have been installed in their final location. The building to house the compressors, controls, and chamber is being constructed on schedule.

Data Reduction

Hugh Bradner

4-Inch Chamber

Analysis is continuing, as described in the preceding Quarterly Report, UCRL-3782.

10-Inch Chamber

The chamber was used during June and July for studying associated production of Λ^{o} and K^{o} particles by 1.1-Bev/c π mesons. Approximately

700 events have been measured on the Frankenstein coordinate reader, and analyzed by means of the IBM-650 machine. Four new IBM programs (Diran, Drandy, Sloppy, Kine) were used along with Hydro II for this analysis.

A study by Dr. Marcello Cresti indicates that there are systematic track distortions in the bubble chamber, caused by the high velocity of liquid hydrogen near the expansion line. Spurious momentum in some cases is as great as 100% for 1-Bev/c tracks of 3-inch length. Attention to timing of chamber expansion and light flash relative to Bevatron pulse, plus correction for the reproducible displacement of track bubbles, still leaves an uncertainty in curvature of 10% for 1-Bev/c tracks of 8-inch length. This uncertainty is approximately 5 times the limit set by multiple Coulomb scatter.

Two short IBM programs (Speedy and Tic) have been written to facilitate this analysis.

Brief tests of distortion in processing Pan-X film indicate that 5- to 10-micron differences can be expected between images that were all 1.000 inch apart before development. Distortions as large as 15 μ are uncommon.

Change in film dimension during measurement on Frankenstein are found to be on the order of 1 μ.

Programs are being prepared for the forthcoming experiment on K^- capture in hydrogen and in deuterium.

15-Inch Chamber

An attempt has been made to produce sharp, fine fiducial marks on the chamber glass. Small ruled gratings, acid-etching technique, and sand-blasting have been tried. An improved acid-etching technique appears most promising.

A test run was made at the 32-Mev linear accelerator, using the 4-inch chamber, with retrodirective prisms in mountings of the type proposed for the 15-inch and 72-inch chambers. Track was adequate; bubbling around the prism mounts was objectionable.

IBM program revisions are continuing.

72-Inch Chamber

The high cost of film has forced us to reconsider the appropriate image size for photography of the big bubble chamber. Theoretical and experimental studies of lens resolution, plus film resolution and distortion, indicate that a 15:1 demagnification may be satisfactory for the present accuracy of chamber distortion, provided that the image contrast under retrodirective illumination is as good as expected from the 4-inch chamber tests.

This change from 10X demagnification to 15X has produced changes in camera and reader design that are not yet all resolved.

Following a suggestion by Alvarez, some special lenses have been designed to compensate for the third-order optical aberrations introduced by the 5-inch-thick bubble chamber window, plus the hydrogen, and the other windows in the optical path. If these compensating lenses are successful, they will permit simple geometrical reconstruction of tracks with the simplicity and moderate accuracy of ordinary cloud-chamber methods.

Physics Research with Liquid Hydrogen Bubble Chambers

Luis W. Alvarez and group

1.1-Bev/c Negative Beam Exposure to the 10-Inch Liquid Hydrogen Bubble Chamber

The present 1.1-Bev/c negative beam contains π^-, K^- and p^- in the approximate ratio of $1 : 10^{-3} : 10^{-5}$. During the period from mid-June until mid-August we have observed approximately 120 double V^0's, 420 single V^0's, and 160 charged V's. Among these events we have definite evidence for the following reactions:

$$\pi^- + p \rightarrow \theta^0 + \Lambda^0,$$

$$\pi^- + p \rightarrow \theta^0 + (\Sigma^0 \rightarrow \Lambda^0 + \gamma),$$

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

$$K^- + p \rightarrow \theta^0 + n,$$

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

$$\Lambda^0 + p \rightarrow \Sigma^+ + n,$$

$$\Sigma^- + p \rightarrow \Sigma^- + p.$$

In addition to the usual charged mode of decay of the θ^0 we have evidence for the more unusual mode of decay into two leptons and a pion, namely, $K^0 e_3$ or $K^0 \mu_3$. At present only qualitative remarks can be made about the angular distributions.

In contrast to the results of the Glaser group at 1.2 Bev/c, the pion reactions listed above that involve Σ mesons show almost complete isotropy.

PHYSICS RESEARCH

Walter H. Barkas in charge

STRANGE-PARTICLE RESEARCH

Walter H. Barkas, Peter C. Giles, Harry H. Heckman, Fred W. Inman, Conrad J. Mason, Norris A. Nickols, and Frances M. Smith

A thesis titled "The Analysis of Hyperfragments from Strange-Particle Interactions" has been completed by Fred W. Inman (and issued as UCRL-3815, June 1957). The hyperfragments were produced by the capture of K^- mesons and Σ^- hyperons in complex nuclei. Approximately 3.2% of the K^--meson interactions led to hyperfragment production. Of 14 hyperfragments that decay mesonically, eight were completely analyzed, and binding energies were determined. Of 64 hyperfragments that decay nonmesonically, one event was analyzed. The binding energies of the Λ^0 hyperons in the hyperfragments are as follows:

$_{\Lambda}H^3$ -1.08 ± 0.72 Mev;

$_{\Lambda}H^4$ 1.56 ± 0.65 Mev;

$_{\Lambda}He^4$ 2.43 ± 0.64 Mev;

$_{\Lambda}He^5$ 2.66 ± 0.39 Mev;

$_{\Lambda}Li^8$ 5.56 ± 0.28 Mev;

$_{\Lambda}Be^9$ 8.9 ± 2.3 Mev (nonmesonic).

Analysis of K^- and charged hyperons has led to the following masses and lifetimes:

K^- mass: 493.2 ± 0.6 Mev;

Σ^+ mass: 1189.3 ± 0.3 Mev;

Σ^- mass: 1195.8 ± 0.7 Mev;

τ_{K^-} : $1.36 \pm 0.20 \times 10^{-8}$ sec ;

τ_{Σ^+}(proton mode): $0.92 \,^{+0.15}_{-0.13} \times 10^{-10}$ sec.

Area scanning in the region of the stopped K^- mesons has yielded ~27 $\Lambda^0 \rightarrow \pi^- + p$ decays to date. From these events, the Q of the Λ^0 decay and the energy and angular distribution of Λ^0's emitted from the K^- interactions can be determined.

We also are investigating the question of parity nonconservation in $\Sigma^{\pm}$ decays. When K^- mesons are captured at rest by emulsion nuclei, the outgoing Σ hyperon and pion define a plane that is related to the production plane. If the Σ-hyperon decay products showed an asymmetry with respect to this plane, this would constitute evidence for the nonconservation of parity in the Σ-decay process. Our data have been augmented with those from other laboratories; the charged-pion modes show no asymmetry, while the proton mode indicates there may be an asymmetry in the decay process. If the distribution is taken to be of the form $1 + a \cos \theta$, where θ is the angle between the normal to the plane and the direction of the decay pion in the center-of-mass system, the asymmetry coefficient a is $-0.28^{+0.17}_{-0.16}$ for the proton mode.

ANTIPROTON INTERACTIONS

Frances M. Smith and Harry H. Heckman

We have analyzed 17 of the 34 antiproton interactions found in a stack of emulsion exposed to ~700-Mev/c antiprotons. The mean free path for the energy interval 20 to 200 Mev is 16.9 ± 4.4 Mev. Of 37 charged pions followed, eight stopped in the stack; seven were negative and one positive. The negatives ranged from 30 to 130 Mev, while the positive was 60 Mev.

THE μ-MESON POLARIZATION IN A STRONG MAGNETIC FIELD

Walter H. Barkas, Peter C. Giles, Harry H. Heckman,
Fred W. Inman, and Frances M. Smith

We have submitted for publication a study of the π-μ-e decay in a strong magnet field. If the muon is completely polarized along its direction of motion, the probability that the electron into which the μ meson decays will be emitted in the angular interval $d(\cos \phi)$ is

$$(1 + a \cos \alpha \cos \phi)(d \cos \phi)/2.$$

Here α and φ are the angles of the μ and electron relative to the magnetic field direction, respectively; a is the asymmetry coefficient of the angular distribution $(1 + a \cos \theta)(d \cos \theta)/2$, where θ refers to the electron direction with respect to the direction of complete polarization. The value of a we obtain is -0.23 ± 0.05.

HIGH-ENERGY β DECAY

James Vedder and Walter Dudziak

The reduction of data from the β-decay experiment with the spiral-orbit spectrometer is continuing. Preliminary results obtained for the N^{12} and B^{12} half lives are 11.5 ± 0.5 and 20.0 ± 0.7 millisecond, respectively. Other studies related to the spiral-orbit spectrometer are the calculation of resolution curves (IBM program) and the electron spectrum from the μ decay.

INELASTIC COLLISIONS OF OXYGEN IONS IN EMULSION

Harry H. Heckman and William G. Simon

Fifty-micron G.5 emulsions were exposed to a beam of 154-Mev oxygen ions from the heavy-ion accelerator. The emulsions are being scanned for inelastic collisions. The results to date on the mean free path for such collisions are:

Energy range of ion at event (Mev)	Experimental mean free path (cm)	Theoretical mean free path (cm)
65 - 117	14.8 ± 1.5	16.2
117 - 154	11.8 ± 1.0	11.5

PHYSICS RESEARCH

Robert W. Birge in charge

CHARGE EXCHANGE OF POSITIVE K MESONS

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

The charge exchange of K^+ mesons was investigated in an experiment at the Bevatron. The K mesons among the particles in a momentum-analyzed beam were individually identified by a velocity-selective counter system. A multiplate cloud chamber, located in the particle beam, was expanded whenever an identified K meson failed to strike a counter located in the chamber behind an absorber of dense material. The experiment was conducted with a tungsten absorber and with one of copper. In this manner only those K particles that underwent charge exchange in the absorber would expand the chamber. It was planned that the decay and interactions of the neutral K's could be studied. A special technique[1] of Bevatron and cloud-chamber operation made it possible to render visible the trajectories of only those changed particles that were associated in time within a few milliseconds with the triggering K particle. Because the beam was spilled out uniformly over more than 200 milliseconds, there was a reduction in background of about a factor of 50.

Approximately 700 pictures were taken, of which about 10% should have been charge-exchange events, while the remainder are inelastic scatters and decays in flight.

To date no neutral K particles have been identified, although a careful scanning of the film has not been finished.

Preparations are under way for an extension of the above investigation to the 30-inch propane bubble chamber with a magnetic field. The charge exchange will take place in the carbon of the propane molecule, thus making the events directly visible.

SCATTERING OF K MESONS ON PROTONS

Leroy T. Kerth, Thaddeus Kycia, and Lud van Rossum

Analysis of data from a recent counter experiment at the Bevatron has been completed. The total cross section of 192-Mev K^+ mesons on protons has been measured and determined as 15.4 ± 3 millibarns.

The design of a counter experiment to measure the differential-scattering cross section of K^+ mesons on protons has been in progress. The present arrangement is suitable for a K-meson energy of 225 Mev.

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[1] Birge, Courant, Lanou, and Whitehead, in a report submitted to the International Conference on Mesons and Recently Discovered Particles, Venice, Italy, September 1957.

Investigations are being made into the possibility of using liquids at high temperature under high pressure for Cerenkov counters in the K-particle selection system. This counter will enable us to measure the differential scattering cross sections at higher energies (to 400 Mev).

TRIPLE-INDEX VELOCITY-INTERVAL CERENKOV COUNTER

Lud van Rossum

A velocity interval counter having three concentric cylinders of different indexes of refraction $(n_1 > n_2 > n_3)$ has been built and tested.

The Cerenkov radiation from particles of velocity β passing axially through the center cylinder (index of refraction n_1) will penetrate into the intermediate cylinder (index n_2), for $\beta \geq 1/n_2$. For particles of $\beta < 1/n_3$, where n_3 is the index of refraction of the outer cylinder, Cerenkov light will remain in the intermediate cylinder. The photomultiplier tube is placed so that only the light from the intermediate cylinder is detected. Thus the counter will count particles in the velocity band $1/n_2 \leq \beta \leq 1/n_3$.

This counter has been partially tested and the predicted efficiencies confirmed. For particles with velocity $1/n_2 \leq \beta \leq 1/n_3$ the counter is 90% efficient, while for particles of $\beta = 1$ it has an efficiency of about 1%.

π-μ DECAY ANGULAR DISTRIBUTION

Jack Sandweiss

We are examining half of a stack of nuclear emulsions exposed to the 66-Mev π^+ beam at the University of Chicago cyclotron. The other half has been examined by Professor C. Lattes and his group at the University of Minnesota. We have found about 1600 π-μ decays by area scanning, and have begun "along-the-track" scanning to minimize scanning bias. In our area-scanned data we find no statistically significant asymmetries. We have also measured the distribution of the angle of the μ trajectory with respect to the plane of production of the pion (here also the plane of the emulsion). We find no evidence for the minimum at zero which Lattes et al. observe. We do observe fewer decays per unit solid angle for angles about 90°. Work is continuing to determine whether or not this is due to scanning bias.

Elastic Scattering of Antiprotons in Nuclear Emulsion

In cooperation with Gerson Goldhaber, the previous measurements have been redone and extended to a projected angle of 1.5°. At the smallest angles the observed distribution agrees well with point-nucleus Rutherford scattering, verifying the scanning efficiency and measuring technique.

In addition, another meter of track has been followed, and in the analysis the results of Amaldi et al.[1] on 1.3 meters of track have been included for a total of 13.4 meters.

[1] Amaldi, Castagnoli, Ferro-Luzzi, Franzinetti, and Manfredini, Nuovo cimento, 5, 1797 (1957).

The data now agree remarkably well with the charged-black-sphere model in the forward hemisphere, although we see no evidence for the rise in the backward direction characteristic of the sharp-cutoff model.[2] In cooperation with Mr. Donald A. Steinberg of the computing group, a program for the IBM 650 to compute the elastic-scattering differential cross section, utilizing the WKB approximation, is nearing completion. This will allow calculation of the scattering expected from (almost) arbitrary real and imaginary potentials.

[2] J. S. Blair, Phys. Rev. 95, 1218 (1954). Our model is the same as in this reference except that we have used the WKB approximation for the Coulomb phase shifts.

THEORETICAL GROUP

David L. Judd

NUCLEAR INTERACTIONS

The study of the elastic scattering of deuterons by nuclei has been concluded and a report on the work is being prepared. The application of the theory to the elastic scattering of 156-Mev deuterons by carbon led to satisfactory agreement with the experimental differential cross section, but it was not possible to explain the large experimental polarization. The various approximations made in the calculation were critically examined to find a possible source for the discrepancy between the calculated and measured polarizations, but with no success. (Warren Heckrotte)

An attempt was made to calculate the charge-exchange cross sections for protons scattered by hydrogen atoms. The idea was to use a Born-approximation trial wave function in a Schwinger variational principle for the scattering amplitude. Preliminary estimates seem to indicate no appreciable improvement over the Born approximation. Because of recent calculations by other authors it has been decided to terminate this project. (Jack Uretsky)

The deuteron pickup process has been treated in the Born approximation by use of the interaction between the incoming particle and all the nucleons of the initial nucleus. Comparison with experimental results gives a nuclear-momentum density distribution of the approximate form $\exp(-E/20)$. Calculations are being made for a more exact solution in which the distortions from the Born approximation are expressed in terms of empirical T matrices representing scattering into intermediate states. (Kenneth R. Greider)

The interaction between a Λ particle and two nucleons is being considered. The calculation is being carried out on the assumption that the interaction is due primarily to the exchange of pions. The role of such three-body forces in the binding of hyperfragments will be examined. (Richard Spitzer)

A study of high-energy collision phenomena, and particularly of associated production in pion-nucleon and nucleon-nucleon collisions, is in progress. We are interested in the role of intermediate-state pair formation in these collisions and in the validity of charge independence in strange-particle production. (Saul Barshay)

A generalized theory of cluster expansions has been developed for application to the kinetic theory of gases. With its aid, work begun elsewhere on the diffraction of neutrons by dense gases, including inelastic as well as elastic processes, has been completed. (Charles Zemach)

NUCLEAR MODELS

Optical-model analysis of low-energy neutron scattering (Bjorklund, Fernbach, and Sherman, Phys. Rev. 101, 1832 (1956)) by nuclei indicates that the imaginary part of the optical-model potential is strongly peaked at the nuclear edge. In an attempt to understand this result, the imaginary potential was calculated for a degenerate Fermi gas completely contained in a large box. It was found as expected that the imaginary potential was peaked near the surface. The maximum value was about 30% greater than the value in the interior region. However, this is substantially less than is found from the optical-model analysis. (Warren Heckrotte)

Work is in progress on the application of the optical model to the inelastic scattering of high-energy protons, with particular reference to the excitation of the 4.4-Mev level in C^{12}. An attempt is being made to include the strong coupling of the excited state in the optical model. (David Thouless)

The systematic study of the deformation energy of a uniformly charged drop was continued. (W. J. Swiatecki)

A paper describing the center-of-gravity theorem for nuclear energy levels (see preceding Quarterly Report) has been completed and is being submitted to the Physical Review. Although the original intent of this project was to study the ground-state properties of Mn^{55}, it has been decided to postpone further work until additional experimental data on neighboring nuclei become available. (Jack Uretsky in collaboration with R. D. Lawson of the Physics Department)

A study is being continued of the influence of the exclusion principle on the effective cross sections of the nucleons in a nucleus. Because the exclusion principle is known to suppress scattering processes involving occupied states, it has usually been assumed that the effective cross section of a nuclear particle is always smaller than that of the free particle. A careful investigation shows that this is not the case; at energies above a few hundred Mev the effective cross section of a nuclear particle will in fact become larger than the free-particle cross section. The origin of this effect may be seen most easily by discussing the problem in configuration space by means of the position correlations of the nuclear particles: if the nuclear particles are uncorrelated in position their effective cross sections may be shown to be the free-particle cross sections. The exclusion principle introduces a correlation that keeps similar particles apart. The destructive interference effect produced in scattering by the hole in the distribution of particles surrounding a given one is the familiar suppression effect, as seen in configuration space. As the energy of the incident particle rises, absorptive and double-scattering effects become important, eventually dominating the effect of destructive interference. The exclusion-principle correlation, by keeping particles apart, tends to keep them out of the "shadows" cast by other particles. Since the nucleons are then caused to present more effective targets than if their position were random, their effective cross sections (i.e., those that enter the formula for the nuclear opacity) are larger than the free-particle cross sections. The effect is,

in a sense, the reverse of that seen in the deuteron cross sections for high-energy incident particles. There, because the deuteron wave function keeps the neutron and proton near each other and leads to "eclipsing," the effective cross section per nucleon is smaller than the free-particle cross section. Studies of the latter effect are continuing as a means of calculating the antiproton-neutron cross section. (Roy Glauber)

Programming of a subroutine to compute solutions and eigenvalues of the spheroidal wave equation in a spheroidal square well is still in progress. As an outgrowth of this work it has been decided to write a new floating-point arithmetic routine for the IBM 701. The coding of this routine is being done by A. D. Johnson. (Jack Uretsky)

MANY-BODY PROBLEMS

The determination of wave functions and energy levels of many-body systems is being studied through both the time-independent and the time-dependent formulations of perturbation theory. A theorem has been proved which demonstrates explicitly the relation between the two, the cancellation of the so-called "unlinked cluster" terms, and the cancellation of errors incurred by omitting the Pauli principle in intermediate states. Improvement of Brueckner's approximations for many-body systems is sought by means of the methods developed. (Nubuyuki Fukuda and Charles Zemach)

Some preliminary calculations were made in connection with a study of certain types of diffraction effects which arise in a Fermi gas of particles enclosed in a box possessing space symmetries. For example, in the case of standing waves in a cylindrical box with reflection symmetry about a plane orthogonal to the axis, there appears a diffraction pattern around the plane of symmetry, which leads to alternating regions of high and low density along planes parallel to the symmetry plane. The possible relation of this effect to the oscillating pattern of fission yield curves is being investigated. (W. J. Swiatecki)

The correlations between spontaneous fission half lives and ground-states mass of heavy nuclei studied previously were examined in the light of more recent experimental data. (W. J. Swiatecki)

PION PHYSICS

The electromagnetic structure of the nucleon has been studied by the same general approach to local field theory as has successfully correlated experiments on the interaction of low-energy pions with nucleons, that is, by dispersion relations. Although a really definitive result has not yet been achieved, it has been shown that the local theory probably will account for both the observed magnetic moment and the radius of the magnetic moment in terms of virtual pion pairs. For understanding of the observed charge distribution in the nucleon, more complicated virtual configurations than pion pairs are certainly required; but it has been shown that in a local theory there is a fundamental difference between the charge and magnetic-moment distributions which permits anomalous behavior in the former. As our understanding of antinucleons and strange particles increases it should be possible, using the formalism developed, to see whether virtual configurations involving these objects will explain the peculiar charge structure. (Geoffrey Chew, Stephen Gasiorowicz, and Robert Karplus)

A systematic study of the nucleon-antinucleon interaction according to the Yukawa theory is being undertaken. It is assumed that outside a distance of the order of the nucleon Compton wave length the interaction between nucleon and antinucleon proceeds by the exchange of pions, that is, by the mechanism that has successfully accounted for ordinary two-body nuclear forces. It is further assumed that, once the cores of nucleon and antinucleon have been drawn into contact by pion exchange, annihilation results. The cross sections produced by this mechanism, at least in the energy range of a few hundred Mev, are determined essentially by the size of the pion clouds and not by the core radii. Since many angular-momentum states are involved and the forces are different in each state, fairly extensive numerical calculations are required and the 650 computer is being employed. (James Ball, Geoffrey Chew, and How-sen Wong)

A dispersion relation has been derived for short-range potential scattering in the presence of a Coulomb field, and on the basis of this result a conjecture has been made as to the Coulomb modifications of the Goldberger relations for pion-nucleon scattering. The new relations contain, in addition to Coulomb phase shifts, only amplitudes that are directly measurable experimentally. The utility of relativistic dispersion relations as a quantitative test of microscopic causality will be substantially increased if the conjecture can be verified. (Geoffrey Chew and H. P. Noyes)

A new project was begun during the last quarter to calculate the cross section for the photoproduction of π mesons from the deuteron. The impulse approximation is being used, together with nuclear amplitudes which were calculated by Chew et al. (Phys. Rev. 106, 1345 (1957)). (Jack Uretsky)

SYMMETRY PRINCIPLES

Furry's theorem was proved for Gell-Mann's model of very strong interactions. It was shown that a closed-loop diagram with an odd number of external pion lines and any number of external photon lines vanishes. This result is due to the global symmetry of the baryon-pion couplings in Gell-Mann's model. (Robert Pugh)

After Lee and Yang raised the question regarding the invariance of weak interactions under space inversion (P), charge conjugation (C), and time reversal (T), many experiments confirmed that both P and C invariances are violated. The question concerning the T invariance has been studied. The conclusion is that the present experimental results are inconsistent with each other even in the range of the present large experimental errors. The possible experiments by which the T invariance can be tested have been listed in a report by Tsuneyuki Kotani, Brief Review of the Allowed Beta Transitions, UCRL-3798, May 1957. (Tsuneyuki Kotani)

The interpretation of the breakdown of the C, P, T conservation laws in terms of the geometry of Hilbert space has been investigated. The geometric nature of that space may be exhibited in terms of a generalized spinor calculus. The usual bras and kets may be identified with a dotted and undotted space of state vectors ψ^N and ψ^N of a contravariant nature.

To these we adjoin two covariant entities ψ_N and $\psi_{\dot{N}}$. The CTP theorem then asserts the existence of a metric g_{MN}, which may be used to lower and raise indices, thus rendering the covariant and contravariant description physically equivalent. T, if conserved, would imply the existence of a $g^{N}_{\dot{N}}$ which could be used to replace undotted co-(contra)-variant indices with dotted co-(contra)-variant indices. A more detailed note on the subject is in the course of preparation. (Maurice Neuman)

Neutrinos as spin one-half particles of mass zero admit a group of transformations that leave free-field Hamiltonian and commutation relations invariant. Interaction Hamiltonians for beta decay are transformed into equivalent Hamiltonians that give the same experimental results. Observable quantities can be expressed in terms of invariant combinations of coupling constants. These invariants, which were put forward in recent papers by Pursey and Pauli, have been investigated in more detail, because they might possibly be useful for the analysis of experimental data. Identities and inequalities between them have been established, and invariance with respect to parity, charge conjugation, and time reversal have been expressed in terms of these invariants. Necessary and sufficient conditions have been given for conservation of lepton charge and (or) two-component theory. The equivalence between the Majorana and Weyl theories of the neutrino is a particular case of the concept of equivalent Hamiltonians. (Gerhart Lueders)

Experimental information on beta decay has been expressed in terms of the foregoing invariants. (Tsuneyuki Kotani and Gerhart Lueders)

The problem of equivalent Hamiltonians (in the sense of Pauli-Pursey) for μ decay has been investigated. Pauli's main idea has been extended so as to include a group of transformations for the electron field that also leads to equivalent Hamiltonians in the usual approximation in which the electron mass is neglected. (R. Gatto)

A note (On the Identity and Parity of K-Mesons and the Parity of Hyperons from a Strong Reaction) on an experiment for the determination of the relative parity of the Σ and Λ particles was written and submitted to the Physical Review for publication. (Saul Barshay in collaboration with Jack Sandweiss)

A paper entitled "Vacuum Electrodynamics on a Merry-Go-Round" dealing with the formulation of Maxwell's equations in a rotating coordinate system has been completed and submitted to the American Journal of Physics. (Jack Uretsky in collaboration with John Ise)

TWO-COMPONENT THEORY OF β DECAY

Dyson and McVoy (Physical Review 106, 1360 (1957)) have calculated the cross sections for the various combinations of forward and backward polarizations of electron and photons in bremsstrahlung and pair production, and it has been shown that this may lead to the possibility of a large-scale persistence of longitudinal polarization in high-energy cascade showers. Monte Carlo calculations are being considered to evaluate the polarization in such showers of relatively low energy. The results sought will be similar to those of R. R. Wilson (Physical Review 86, 261 (1952)), except that they will include polarization effects. (LeRoy F. Cook, Jr. and Neville Williams)

The paper on the general formalism of angular correlation and polarization discussed in the previous progress report has been submitted for publication in the Physical Review. (Richard Spitzer and Henry Stapp)

A more detailed version of the above paper, including a derivation of the general equations that separate the physical properties of interactions from the geometrical ones, has been prepared for publication as a laboratory report. (Richard Spitzer)

A two-neutrino theory has been constructed for which the Fierz terms automatically vanish, so that both S and V can be present even if time reversal is satisfied. The theory postulates a symmetry principle for weak interactions from which the rule by which the left-handed neutrino and the right-handed neutrino are coupled follows uniquely. This rule is different from that used by Mayer and Telegdi in their twin-neutrino theory. The advantage of this theory is that it gives a consistent description of all weak interactions and it explains (apart from the nonlocal effects proposed by Lee and Yang) both the ρ value and the equality of the magnitudes of g_V and g_A in μ decay. (R. Gatto)

MUONS

Calculations are in progress on μ decay in the two-component theory, using lepton conservation. (Sidney Bludman and Abraham Klein)

An investigation of the μ-meson decay spectrum is under way. A parity-conserving electron wave operator and a parity-nonconserving neutrino wave operator are observed to satisfy the same one-parameter field equation. The resulting spectrum is expected to be almost that resulting from the two-component neutrino equation. (Robert Pugh)

By use of a two-component theory of the neutrino, the capture process of a μ^- by a proton is analyzed. In process $\mu^- + p \rightarrow n + \nu$, with a completely polarized μ^-, the angular distribution of the neutron is of the form $1 + a \cos \theta$, where θ represents the angle between the spin direction of μ^- and the momentum of the neutron; a has the same values (1) for S- and V-coupling types and (1/3) for T- and A-coupling types, respectively. If we can measure the polarization of the neutron in this process, we can distinguish the S-coupling type from other coupling types. This is because in S coupling, polarized neutrons are not observed, while in the other cases (V, T, and A) the neutron is polarized. (Tsuneyuki Kotani)

A calculation is being carried out on the absorption of μ^- by deuterium, with the hope that someone willing to learn about the μ-absorption interaction would like some day to carry out this difficult experiment. (R. Gatto)

The calculations of the properties of μ^-mesic molecules are being continued. An IBM 701 program has been written to calculate the wave functions for the p-p, p-d, and d-d systems, together with the energies of the bound states and the normal and exchange scattering of mesic atoms for protons and deuterons. (Stanley Cohen, David L. Judd, and Robert J. Riddell)

MISCELLANEOUS

The decay processes of fundamental particles are being surveyed. This is being done by selecting simple renormalizable couplings and applying perturbation theory. (Owen Eldridge)

A study is being made of various interpretations of the quantum theory. (Coates R. Johnson)

NUMERICAL ANALYSIS

Mathematicians in the theoretical group have been occupied as follows during the preceding quarter.

Programming and debugging of a program for finding wave functions and energy eigenvalues of the μ-mesic molecules for the case of equal atomic masses was continued. (Victor Brady, for Stanley Cohen, David Judd, and Robert Riddell)

A program used in the analysis of hyperfragment decays was revised and re-run. (Victor Brady, for Fred Inman)

In continuous-flow separation methods, such as liquid-liquid extraction, the degree of separation is improved by increasing the local rate of interphase transfer, but is impaired by longitudinal diffusion. An involved analytic solution has been derived by T. Miyauchi which gives the concentration profiles in a separation cascade or column as a function of material-transfer rates, longitudinal-dispersion coefficients, partition ratio, and flow rates, which are each considered as constant throughout the column. Tables are needed that will tabulate concentration profiles for at least 360 typical combinations of the operative parameters. The computation of these tables has been programmed for the IBM 701. (Alice McMullen, for Theodore Vermeulen)

An iterative scheme for Simpson's rule has been devised which will permit successive approximation of the integral to a preassigned degree of accuracy without redundant calculation of the integrand. A program is being developed for this scheme, using the Bell Lab. Interpretive Routine. If successful it will be rewritten for the 650 with built-in floating point. (Kent Curtis and Henry Silva)

A program has been written to compute the energy and angular distribution of neutrons from the reaction α + nucleus → 2n + nucleus. A statistical model of the nucleus was assumed. (Kent Curtis and Robert Freeman, for William Wade and Bernard Harvey)

Three general utility subroutines were written and checked out for the IBM 701. Descriptions and program decks are available upon request. The routines are (a) square root; (b) table look-up and tally; and (c) exponential for large values of x. (Robert Freeman)

A general utility program for the solution of a set of simultaneous first-order differential equations is being devised. When completed the program will permit the solution of n simultaneous first-order equations, n/2 simultaneous second-order equations, n/3 simultaneous third-order equations, etc., where the maximum value of n will be of the order of 18. The program will be written for the 650 with built-in floating point and index registers. The five-point integration formula of Milne will be used. (Kent Curtis and Robert Harvey)

A translating routine was written for use with the automatic plotter that we now have in operation. The translating routine will translate the three-digit numbers intended to represent the x and y coordinates of a point by arbitrary and independent amounts, and punch cards with the translated coordinates in a convenient format for use with the plotter. (Kent Curtis and Donald Steinberg)

The programming for the IBM 701 of a study of the reaction cross section for the emission of two nucleons by a heavy nucleus excited by a proton, using the impulse approximation, has been completed. Assembly of the program and debugging is in progress. (Tom Clements, for Lester Winsberg)

A program was written to calculate the radiative correction for electrons that leave the source of a spiral-orbit spectrometer. The energy distribution of the electrons as they leave the source is determined by a separate program which takes into account the scattering in the source of the originally monoenergetic electrons. (Michael Lourie, for Walter Dudziak)

Another program was written to calculate the resolution of the spiral-orbit spectrometer on the median plane as a function of the magnetic field and dimensions of the source detector and slit. This was done by means of a closed expression that gives the probability of reaching the focusing orbit for various electron energies and source sizes. (Michael Lourie, for Walter Dudziak)

The DUAL floating-point routine for the IBM 701 computer has been rewritten to use a binary floating exponent. It is expected that this will considerably increase the speed of floating-point operations as well as the flexibility and accuracy of the interpretive system. (A. D. Johnson)

The program to compute the spheroidal wave functions for a specific nuclear potential, which was reported in the preceding Quarterly, is being rewritten, using the modified floating-point routine. (A. D. Johnson, for Jack Uretsky)

A routine was written that evaluated the volume of a blood cell by Simpson's rule, assuming cylindrical symmetry for the blood cells and using as input the thickness of the cell at several points along a diameter. (Morton Davis, for Charles Sondhaus)

Two programs were written to calculate phase-space integrals for three-particle systems in which the maximum momentum was evaluated and the phase-space volume was computed. (Morton Davis, for Robert Tripp and for Roger Douglas and Myron Good)

A routine is being devised to get a least-squares fit to data, either by polynomials or by preassigned functions. The routine will be written for the 650 with built-in floating point and index registers, and will compute the coefficients in the least-squares fit, the residuals at each observation point, and the mean square deviation in the coefficients. (Kent Curtis and Morton Davis)

A program has been written to solve two simultaneous transcendental equations to determine focal length of 8-inch quadrupole magnetic lenses. (Marjory Simmons, for Lewis Agnew and William B. Johnson)

Some cyclotron orbits were calculated on the differential analyzer to assist in determining the focusing properties of the cyclotron field for orbits that deviate from the standard orbit by small amounts between radii of 80 inches and 120 inches. (Robert Harvey and Jonathan Young, for Roy Haddock)

Some maintenance work was done on the analyzer. All the wear plates were resurfaced and most of the disc rims were resurfaced. (Robert Harvey and Jonathan Young)

The computation and tabulation of the Racah W coefficients, which were reported in the last progress report, have been completed. (Ardith Kenney, for Jack Uretsky)

The data-reduction programs for use with the 10-inch bubble chamber by the Alvarez group are nearing completion. A brief resume of the programs, stating the function and author of each, follows:

Hydro II Analyzes events that have been processed on the Frankenstein. Each track of an event is reconstructed in space, then the curvature and dip angle are determined by a least-squares technique. This program calculates the momentum of each track, the initial and final coordinates in space, the direction cosines at the beginning and end of each track, and the length. In addition the root-mean-square deviation is calculated for the fit in x and y, and also in z, as well as the errors in the dip angle, sagitta, and momentum. (Charles Stableford)

Speedy Accepts a set of track coordinates measured on Frankenstein. These tracks are cut into shorter segments, which are then analyzed by Hydro II to determine the errors in momentum as a function of the track length. (Charles Stableford)

Raps Takes the same set of track coordinates as Speedy, but rather than cutting the track into segments, selects only the alternate coordinates. These new tracks are analyzed by Hydro II to determine the errors in momentum as a function of the number of track coordinates. (Richard Mitchell)

Tic Analyzes Hydro II output to determine the spurious curvature due to turbulence of liquid hydrogen in various regions of the bubble chamber. (Charles Stableford)

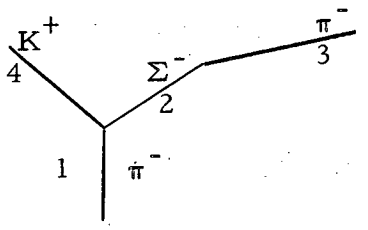
H II to H I Receives Hydro II output and converts this into Hydro I output. This output is then used as input into Diran and (or) Drandy. (Frank Solmitz)

Diran Calculates the spherical coordinates of each track, i.e., $\lambda \equiv$ dip angle and $\phi \equiv$ the azimuthal angle. It also computes the included angle between all possible pairs of tracks for an event, and connects specified vertices to simulate straight tracks. All angles are calculated in degrees. (Charles Stableford)

Drandy Calculates the momentum of V particles from the angles between the neutral particle and the two charged particles in the event, assuming that the neutral particle is either a θ^o or a Λ^o. This program includes all of Diran and is designed to function just as Diran for particles other than V particles. (Lynn Stevenson)

Sloppy Was designed to carry out calculations on the following type of event:

$$\pi^- + p \rightarrow \Sigma^- + K^+; \quad \Sigma^- \rightarrow \pi^- + n,$$



The program assigns errors to the momenta and direction cosines and calculates the relevant included angles and the corresponding errors. In addition the quantities $\hat{3} \cdot (\hat{1} \times \hat{2})$, $\hat{3} \cdot (\hat{1} \times \hat{4})$, and $\hat{2} \cdot (\hat{1} \times \hat{4})$, are computed (where $\hat{i}$ is a unit vector along track i). Finally the dihedral angle between production plane and the decay plane of the Σ particle is calculated. (Harold Hanerfeld and Frank Solmitz)

Skippy Converts Hydro II output into the half-word format for the 701. The motivation for this program was to produce input cards for the π p θ^o Λ^o 701 program. (Charles Stableford)

<u>π p $\theta^{o}\Lambda^{o}$</u> Is now being developed for the 701 to analyze the reaction

$$\pi^{-} + p \rightarrow \theta^{o} + \Lambda^{o} \quad \begin{cases} \theta^{o} \rightarrow \pi^{+} + \pi^{-}, \\ \Lambda^{o} \rightarrow p + \pi^{-}. \end{cases}$$

The program takes measured values of the momenta and directions with preassigned errors, and finds through χ^{2} fit the best set of momenta under the constraint of energy-momentum conservation for each of the three processes. (Seymour Singer)

PHYSICS RESEARCH

Edward J. Lofgren in charge

30-INCH PROPANE BUBBLE CHAMBER DEVELOPMENT

Warren W. Chupp and Sulamith Goldhaber

During this period we have been participating in the construction of the "30-inch propane bubble chamber" in collaboration with Professor Wilson Powell's group. Aside from the basic design considerations, considerable effort has gone into the design of special devices and selection of materials that will add to the reliability and safety of operation.

A preliminary test without magnetic field has shown that the chamber shows "tracks" and that only minor changes and additions are necessary.

The first experiment we plan to carry out is an investigation of K^+ and proton interactions at a K^+ energy of approximately 250 Mev. In order to compare our previous emulsion results and to check the K^+-detection efficiency, an emulsion stack will be exposed in the same separated K^+ beam simultaneously with the bubble-chamber run.

INTERACTION CROSS SECTION OF NEGATIVE K MESONS IN THE ENERGY INTERVAL T_K = 100 to 200 Mev

Sulamith Goldhaber, Warren W. Chupp, and Susan Klein

The scanning of a stack exposed to a negative beam of momentum 500 Mev/c is in progress. The exposure was carried out at an angle $\theta_{lab} = 30^o$ to the incident proton beam. The composition of the beam at the position of the emulsion stack (target-to-stack distance $\tilde{=}$ 19 ft) is about 2000 minimum background tracks to one K^- meson. It is hoped to obtain the following information from the analysis of the scanning data:

a. The K^--interaction cross section with complex nuclei at T_K = 100 to 200 Mev. (To date we find the mean free path in that energy interval to be $\lambda_{100-200} = 21.3 \pm 5.5$ cm.)

b. The K^--H scattering cross section and absorption cross section in the above energy interval.

c. The K^--nucleus potential by the method of a partial-wave analysis from the experimentally determined differential elastic-scattering cross section.

The table below summarizes the data found to date in the stack under discussion.

Table II

Data from scanning of emulsion stack exposed to 500-Mev/c negative beam

Kinetic energy, T_{K^-} (Mev)	Path length scanned (cm)	No. of interactions	λ (cm)	K-H scatt.	K-H abs.
20-100	86	2	-	0	1($K^- + H \rightarrow \Sigma^- + \pi^+$)
100-200	319.7	15	21.3±5.5	0	0
0(K^- at rest)	-	17	-		1($K^- + H \rightarrow \Sigma^+ + \pi^+$)

EXPERIMENTS ON ANTINUCLEONS AND K PARTICLES

Bruce Cork, William Galbraith,* Glen Lambertson, William Wenzel, and Charles Coombes

K-μ-e Asymmetry

The apparatus, briefly described in the preceding report, to detect the stopping μ meson and decay electron has been assembled and tested with cosmic-ray μ mesons. Some of these μ mesons traveling at small angles about the vertical direction come to rest in an aluminum absorber about which are placed plastic scintillators 1 square foot in area, three above and three below. The incoming μ meson and the direction of the decay electron are readily identified by the response of these scintillators. Aluminum wire has been wound around the absorber and a uniform magnetic field can be applied to produce precession of the μ meson. The preliminary test showed that decay electrons from stopping μ mesons were being detected at the rate of approximately one every 3 minutes, but not enough data have been obtained for any conclusion to be drawn about the asymmetry of the cosmic-ray μ's. The cosmic-ray experiment has been discontinued to prepare for the Bevatron experiment.

The electronic circuits for the K-meson selection system have been assembled and tested, and the apparatus is being set up near the Bevatron. Initial tests indicate that careful shielding of the scintillation stack is necessary to reduce the background due to accidental coincidences.

Electrostatic Beam Separator

The separator is contained in an evacuated steel enclosure 20 ft long and about 20 by 20 in. in section. The beam enters and leaves through 10-mil mylar windows 8 in. in diameter. This assembly has been vacuum-tested and is tight. Coil windings outside the vacuum system can be used to produce a magnetic field of up to 200 gauss at right angles to the electric field between the electrodes. The magnetic system and associated water circuits have been tested. The two 160-kv (+ and -) high-voltage supplies are nearly complete, but have not yet been tested. The high-voltage electrodes will be about 19 feet long and 8 in. wide, with a separation that can be varied from 2 to 7 inches. A sample electrode is ready for high-voltage test in the vacuum.

Antinucleon Experiments

We are preparing an experiment to measure cross sections of antiprotons in matter. The chief purpose of this experiment is to extend measurements of the $p-\bar{p}$ total cross section to energies lower than 200 Mev.[1]

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*Commonwealth fellow. On leave of absence from A.E.R.E., Harwell, Berks, England.

[1] Cork, Lambertson, Piccioni, and Wenzel, Phys. Rev. 107, 248, (1957).

A hydrogen target 1 ft thick in the beam direction is being designed for this purpose. The target will be of sufficient diameter to permit measurement of the proton-antiproton differential-scattering cross section for laboratory angles up to 45°. The range of antiproton momenta to be studied is 500 to 900 Mev/c. In order to obtain a large flux of antiprotons at low momentum, an 8-in. quadrupole magnet will be used as near as possible to the internal Bevatron target. This will be followed by the "parallel plate" electrostatic beam separator, to separate particles of a given momentum according to mass.

PHYSICS RESEARCH

Burton J. Moyer in charge

ANGULAR DEPENDENCE OF NEUTRON SPECTRA FROM 32-Mev PROTON BOMBARDMENT OF THIN TARGETS

Harold E. Adelson, Hoyt A. Bostick, and Charles N. Waddell

Work is continuing on the measurement of neutron-energy spectra from thin targets bombarded by 32-Mev protons at the linear accelerator, using the hydrogen bubble chamber as a neutron spectrometer.

In order to measure the resolution of the bubble chamber in its present position in the outer bombardment area of the linear accelerator, we utilized a source of 14-Mev neutrons produced at the normal target position. The neutrons were produced by bombarding a titanium-tritium target with deuterons accelerated in the Van de Graaff generator that is normally used as the injector for the linear accelerator. The deuterons were brought to the outer bombardment area by passing them through the linear accelerator tank, then deflecting them with a steering magnet, and finally focusing them on the target with a set of quadrupole magnets.

The monoenergetic neutron spectrum was measured with no collimator and with three different collimators placed between the target and the bubble chamber. The recoil proton tracks were measured with a Benson-Lehner coordinate-measuring "Oscar," and the neutron energy spectra were calculated with the IBM 650 computer. With no collimator a line spectrum of the proper energy was observed. However, resolution was considerably improved with collimation, and the best collimator gave a line of 1.3 Mev full width at half maximum for the 14.1-Mev neutrons.

This collimator was then used in some test runs with 32-Mev protons on several targets. The number of background neutrons, measured by placing a brass plug in the collimator hole, was found to be less than 5% of the direct neutron flux from the target.

The experiment has been temporarily interrupted by a breakdown of the Van de Graaff generator.

PRODUCTION OF θ^0 MESONS IN THE BEVATRON TARGET

John O. Osher and Sherwood I. Parker

There has been little opportunity to extend the results of this experiment since the preceding report period, but the following additional information has been secured. The production of θ^0 mesons from proton collisions with hydrogen nuclei is not more than one-third the yield from proton collisions with deuterium nuclei, and, in fact, the hydrogen yield is statistically consistent with zero at 3 Bev. This result is in agreement with the work of Collins et al. at Brookhaven. At 5 Bev the p-p yield is still considerably lower than the p-d yield, but good quantitative numbers are not yet in hand.

At the time of this report this problem is being further studied and the angular distributions of the production of the θ^0 mesons will be investigated. It is also hoped that the branching ratio in their decay by the neutral and charged-pion modes can be measured.

COSMIC-RAY NEUTRON EXPERIMENT

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

The neutron detectors used in the experiment to measure the cosmic-ray neutron-energy spectrum have been returned to UCRL from Albuquerque, and during the past 3 months calibrated with several different energy neutron sources. The calibration program is nearly complete, and a preliminary neutron-energy spectrum has been derived from the detector counting rates and absolute counting efficiencies. The spectrum is roughly $N(E) = kE^{-1.5}$ from 0.1 Mev to 1 Bev. We are trying to extend the measurements below 0.1 Mev by using indium foils and other low-energy detectors. Also we are preparing to determine the sea-level counting rates of the detectors.

Because the attenuation mean free path for neutrons in the atmosphere as measured by a bismuth fission chamber is considerably longer than as measured with low-energy neutron detectors, both in this and in previous experiments (220 g/cm^2 as compared with 160 g/cm^2), we are trying to measure the attenuation mean free path of Bevatron neutrons to see how it compares with our measurements.

BEVATRON NEUTRON CROSS-SECTION MEASUREMENTS

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

An experiment has been started to measure the diffraction and absorption cross sections of several elements, using ~4-Bev neutrons from the Bevatron. Data are being taken with a counter telescope using an anti-coincidence counter, a converter, and then coincidence counters. The device responds to high-energy charged particles produced in the converter by incident neutrons. A gas Cerenkov counter is being used so that only high-energy particles will be detected. The Cerenkov counter used now will count π mesons of greater than 1.5 Bev only. This puts a threshold of about 2 Bev on the neutrons that the telescope will count. This Cerenkov counter has been calibrated by use of synchrotron electrons and Bevatron π^- mesons, and operates satisfactorily.

CLOUD CHAMBER STUDIES

Wilson M. Powell in charge

Experiments with Diffusion Chamber

6-Bev n-p INTERACTIONS

Fred N. Holmquist

The most noteworthy result of the present endeavor to measure and analyze the 522 multiprong events observed in the 1955 n-p Bevatron experiment using a hydrogen-filled diffusion cloud chamber is the rather striking evidence for the existence of the (3/2, 3/2) isobaric nucleon, in events of charge configuration $n + p \rightarrow p + n + \pi^+ + \pi^-$. The large range of energetically possible Q values permits a broad investigation of this and other isobars. In the above reaction both nucleons may be assumed excited to the (3/2, 3/2) isobaric state, with subsequent decay via pion emission in which the proton and positive pion are associated in decay 21 times out of 22. The $Q(p, \pi^+)$ and $Q(n, \pi^-)$ distri utions are then phenomenologically related to the interaction cross section observed in pion-nucleon scattering.

To date about 200 of the 473 three-prong events have been analyzed by use of an IBM digital computer. Of these about half are more or less unambiguous (to within a π^0 for events of more than one neutral particle coming off), and of these 57 are probably of charge configuration $n + p \rightarrow p + n + \pi^+ + \pi^-$.

It has been found that the use of weighted histograms rather than histograms is of definite advantage in plotting Q-value distributions. The weighted histograms, which contain the additional information of errors on individual Q values, have the property of narrowing the 0.14-Bev peak and smoothing out the histograms. Both the $Q(p, \pi^+)$ and $Q(n, \pi^-)$ distributions show the characteristic peak at 0.14 Bev, whereas the $Q(p, \pi^-)$ and $Q(n, \pi^+)$ distributions do not. By the adding together of $Q(p, \pi^+)$ and $Q(n, \pi^-)$ distributions the statistics are doubled, and possible bias effects are believed to be effectively reduced. That this distribution fits so well to the π^+-p interaction cross section provides, we believe, the best evidence to date--if not the first conclusive evidence--for the existence of the (3/2, 3/2) isobaric nucleon.

Progress continues on measuring and analyzing the remainder of the events.

Equipment and Techniques

30-INCH PROPANE BUBBLE CHAMBER

Wilson M. Powell and group

Most of the cloud chamber group's effort during this quarter was devoted to preparing the 30-inch propane chamber for a Bevatron run using a separated K^+ beam.

Assembly of components was completed July 26, and a test run in the Building 80 parking lot successfully showed sensitivity to minimum-ionizing particles. No difficulties developed during this short test period. Work is continuing on various minor improvements and on preparation for moving the chamber to the Bevatron.

PAPER SUBMITTED

A paper by Robert H. Good, "Continuously Sensitive Bubble Chamber," has been sent as a letter to the Editor of the Physical Review.

PHYSICS RESEARCH

Emilio Segrè in charge

ANTIPROTON STUDIES

Antiproton Cross Sections*

The run ended in December 1956 has been completely analyzed and the results are reported in three papers submitted to the Physical Review.[1, 2, 3]

Further antiproton studies should try to resolve some apparent difficulties in the elastic-scattering cross section for p-$\bar{p}$. The experiments by Cork, Lambertson, Piccioni, and Wenzel[4] and by us are not easy to reconcile. In the former experiment one measures the total cross section, in ours the annihilation inelastic and wide-angle elastic cross sections. The difference between the two measurements gives the elastic scattering--mainly diffraction. If the numbers are taken at their face values there is too little elastic scattering at 450 Mev, at least for the usual nuclear models.

Concerning the annihilation process itself, the photographic studies proceed, regularly accumulating better statistics. We now have about 200 stars, at present in different stages of analysis (by Gerson Goldhaber, Theodore Kalogeropoulos, and Rein Silberberg). The next irradiation should be the final one for some time to come, giving approximately 1000 stars. The photographic work has been facilitated considerably by the new purified beam (see below).

Annihilation in hydrogen will be studied in cooperation with the bubble chamber group (under Luis W. Alvarez and Wilson M. Powell). The first step necessary will be the further purification of the antiproton beam, for which preparations have been made by improving the system described below.

We expect also to collect some further data on production cross sections in hydrogen and carbon.

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[1] Agnew, Chamberlain, Keller, Mermod, Rogers, Steiner, and Wiegand, Experiments on Antiprotons: Cross Sections of Complex Nuclei, UCRL-3875, July 1957.

[2] Chamberlain, Keller, Mermod, Segrè, Steiner, and Ypsilantis, Experiments on Antiprotons: Nucleon-Antiproton Cross Sections, UCRL-3876, July 1957.

[3] Button, Elioff, Segrè, Steiner, Weingart, Wiegand, and Ypsilantis, Antineutron Production by Charge Exchange, UCRL-3883, July, 1957.

[4] Cork, Lambertson, Piccioni, and Wenzel, Cross Sections of Antiprotons in Hydrogen, Beryllium, Carbon, and Lead, UCRL-3650, Feb. 1957.

We have continued the scanning and analysis of the antiproton stack exposed in the separated antiproton beam.[5] To date we have found 130 antiprotons that interacted in the stack. The stack consisted of 200 Ilford G.5 emulsions (15 by 23 cm by 600 μ). It was exposed at the Bevatron for a total integrated proton flux on the target of 4×10^{13} protons. The antiproton emission angle in the laboratory system was about 0°. Some of the details of the focusing properties and of the beam separation are given herewith.

A Separated Antiproton Beam

Owen Chamberlain, Gerson Goldhaber, Louis Jauneau, and Emilio Segrè

In Fig. 1 we show the magnet setup for the exposure. The entire trajectory was inside a series of helium-filled bags in order to reduce multiple scattering.

The principle of the beam separation is as follows: A beam of 819-Mev/c negative particles is selected from a carbon target in the Bevatron by use of an 8-in. quadrupole magnet Q1 and the analyzing magnet M1 (the magnet M2 takes care of some finer steering effects.) This beam, having a momentum spread of ± 4%, is brought to a focus at F1. The 4-in. quadrupole magnet L acts as a field lens. At F1 we have placed a wedge-shaped LiH absorber (19.8 g/cm^2, median thickness), which alters the momenta of antiprotons and pions by different amounts, so that they can be separated. The resulting momenta are 700 Mev/c for protons, 777 Mev/c for pions. The wedge shape of the LiH absorber (maximum difference in thickness 4 g/cm^2) preserves the momentum spread in the antiproton beam at ± 4%.

The quadrupole magnet Q2 has the function of refocusing the beams of different momenta at F2, while the analyzing magnet M2 separates the focal spots by about 6 in. The magnet system is so designed that although there is a horizontal momentum spread of ± 4% at F1 (compare Fig. 2), the beam is refocused to a final image at F2. The general setup of magnets and quadrupoles is the same as that used for the counter experiment, but with one addition. A final magnet Mc was added just ahead of the second focus. This had the effect of clearing out positive particles, which are produced by edge scattering of the pion beam as it traverses the last quadrupole.

The beam separation as a function of LiH absorber is given in Fig. 3. The amount of absorber used (19.8 g/cm^2) produces a beam separation in the above geometry of about 6 in. The antiproton attenuation is due to multiple scattering, which makes part of the beam miss the quadrupole Q2, and to the nuclear interactions in the LiH absorber. Figure 4 gives the computed attenuation factor as a function of the beam separation,

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[5] Chamberlain, Goldhaber, Jauneau, and Segrè, A Partially Separated Proton Beam, in Physics Division Quarterly Report, UCRL-3689, Feb. 1957.

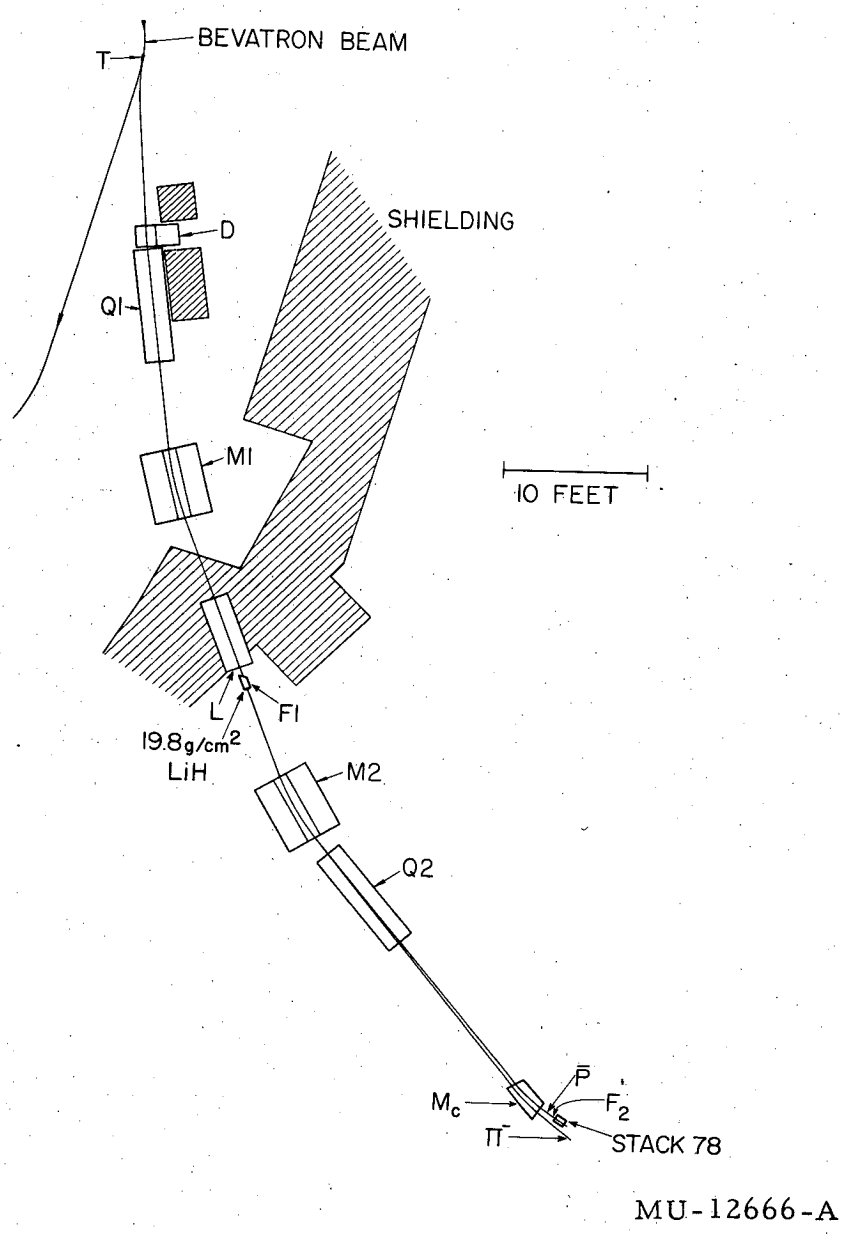

Fig. 1. The exposure geometry.

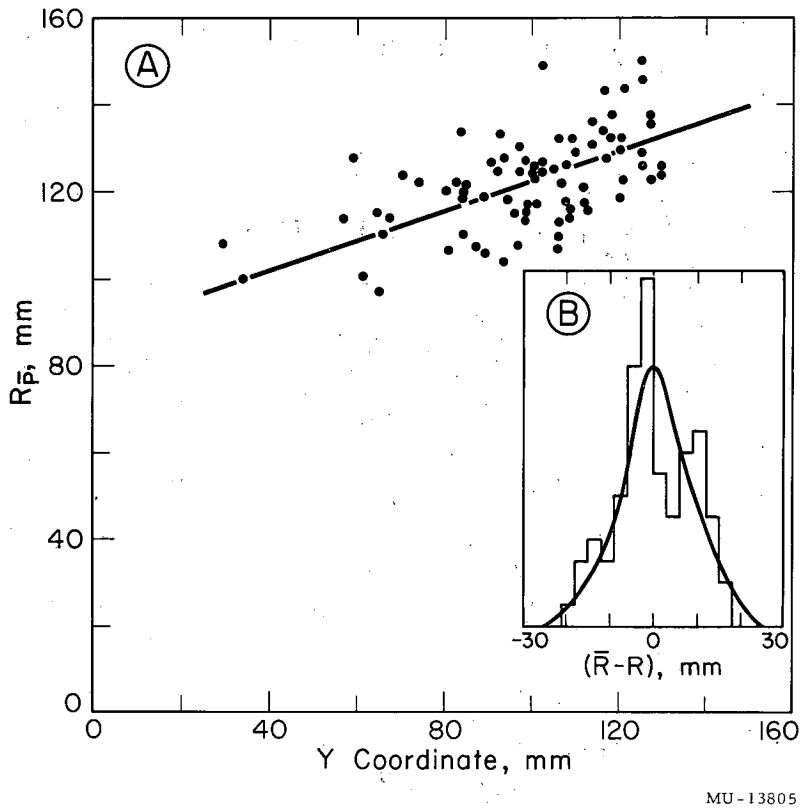

Fig. 2. In Part A the range of stopping antiprotons is plotted as a function of the entrance Y coordinate. The curve gives the mean antiproton range, $\bar{R}$. The insert, Part B, shows the spread in range around $\bar{R}$. The half width at half maximum is about 10 mm. $\Delta R/R$ is thus $\pm$ 0.083, which corresponds to a momentum spread of $\Delta\rho/\rho$ equal to $\pm$ 0.027.

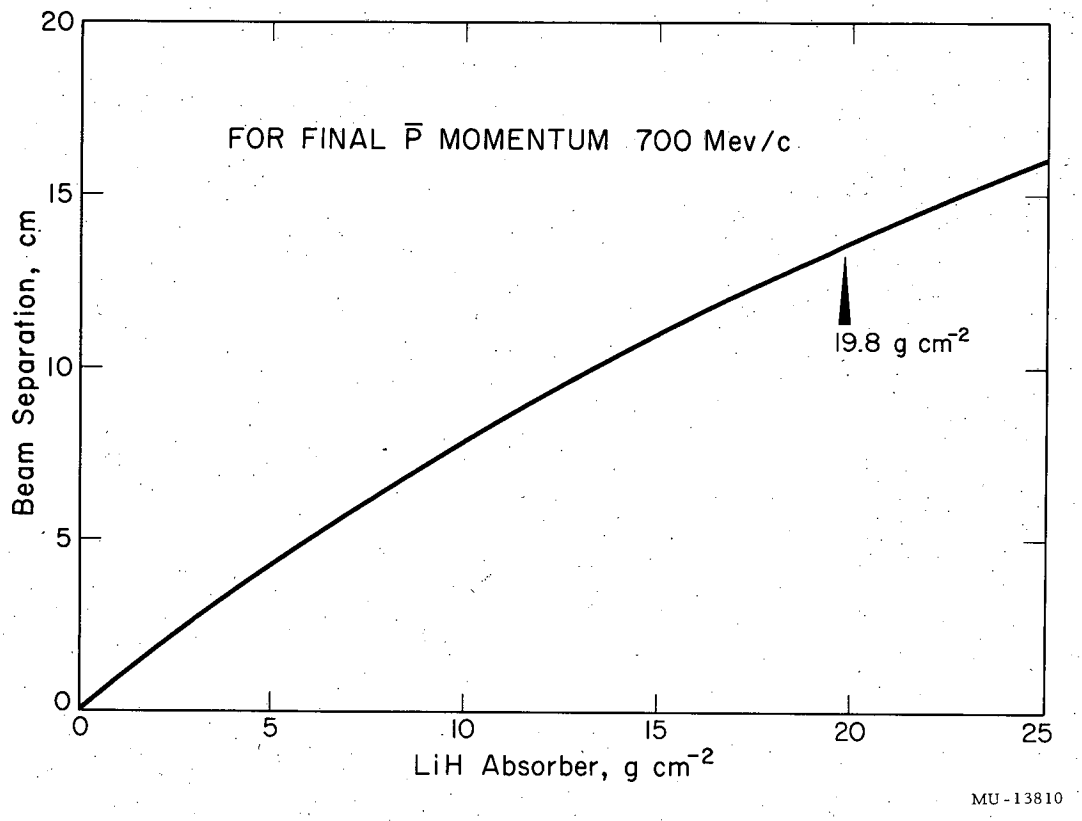

Fig. 3. The separation between the antiproton and pion beams as a function of lithium hydride absorber thickness. This curve applies to the geometry shown in Fig. 1 and is for a final antiproton momentum of 700 Mev/c. The actual absorber used was 19.8 g/cm^2.

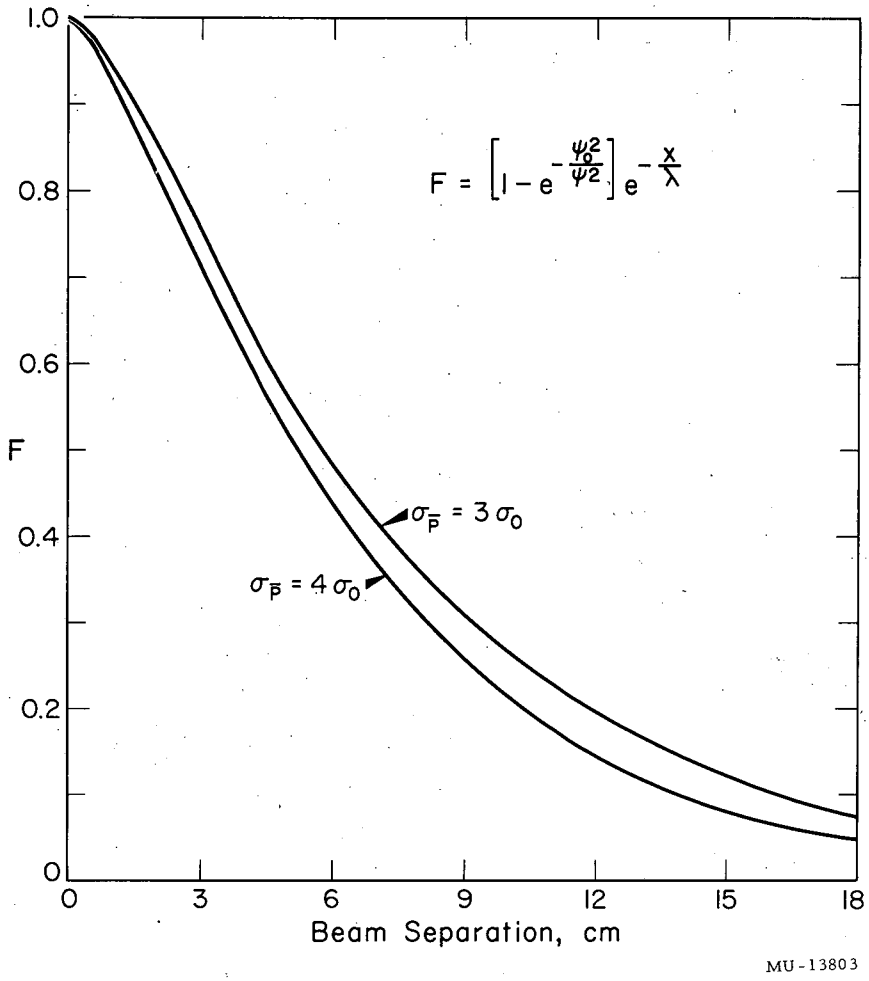

Fig. 4. The antiproton-reduction factor F as a function of antiproton- and pion-beam separation. The total antiproton cross section on lithium hydride down to a 1^{o} cutoff angle has been estimated as lying between 3 to 4 times σ_0, where $\sigma_0 = \pi(1.2 \times 10^{-13} A^{1/3})^2$ cm^2.

$$F = [1 - \exp(-\psi_0^2/\psi^2)] \exp(-\psi/\lambda),$$

where ψ_0 is the aperture angle of the quadrupole Q2, ψ is the mean multiple scattering angle, λ is the mean free path for antiprotons in LiH (this mean free path corresponds to the total antiproton cross section down to an angle of 1^o), and x is the thickness of LiH in g/cm^2. For the total antiproton cross section, we have used the values 3 and 4 times σ_0, where

$$\sigma_0 = \pi(1.2 \times 10^{-13} A^{1/3})^2 \text{ cm}^2.$$

Figure 5a gives the horizontal distribution of the light particles without the LiH absorber. Figure 5b shows the corresponding distribution with the LiH absorber in place. The position of the stack is also shown.

Figure 6 gives the vertical beam distribution as observed in Stack 78. Both the light-particle flux and the antiproton flux are given. Figure 7 gives the horizontal beam distribution.

The composition of the light-particle beam (π, μ, and e), which appears as background to the antiproton beam in Stack 78, was obtained as follows: The density of π-meson stars was obtained by area scanning in this stack; by comparing this density with the light-particle flux, we found that 4% of this flux consisted of pions. By counting the number of light particles across one plate in the beam direction, we obtained the characteristic increase in intensity due to electron multiplication. Figure 8 shows the resulting distribution plotted in units of the radiation length in emulsion. From the position and height of the maximum in the shower curve, we find that about half the remaining light particles must be electrons; the rest, then, are μ mesons.

The separation was thus very effective in removing the pions, but still leaves a large number of electrons and μ mesons as contaminants of the antiproton beam.

The ratio of antiprotons to light particles (π, μ, and e) at the leading edge of the stack is $\sim 1/5 \times 10^4$. This number, when compared with earlier exposures at 700 Mev/c,[6] shows an improvement factor in this ratio of about 10.

[6] The Antiproton Collaboration Experiment, Phys. Rev. 105, 1037 (1957).

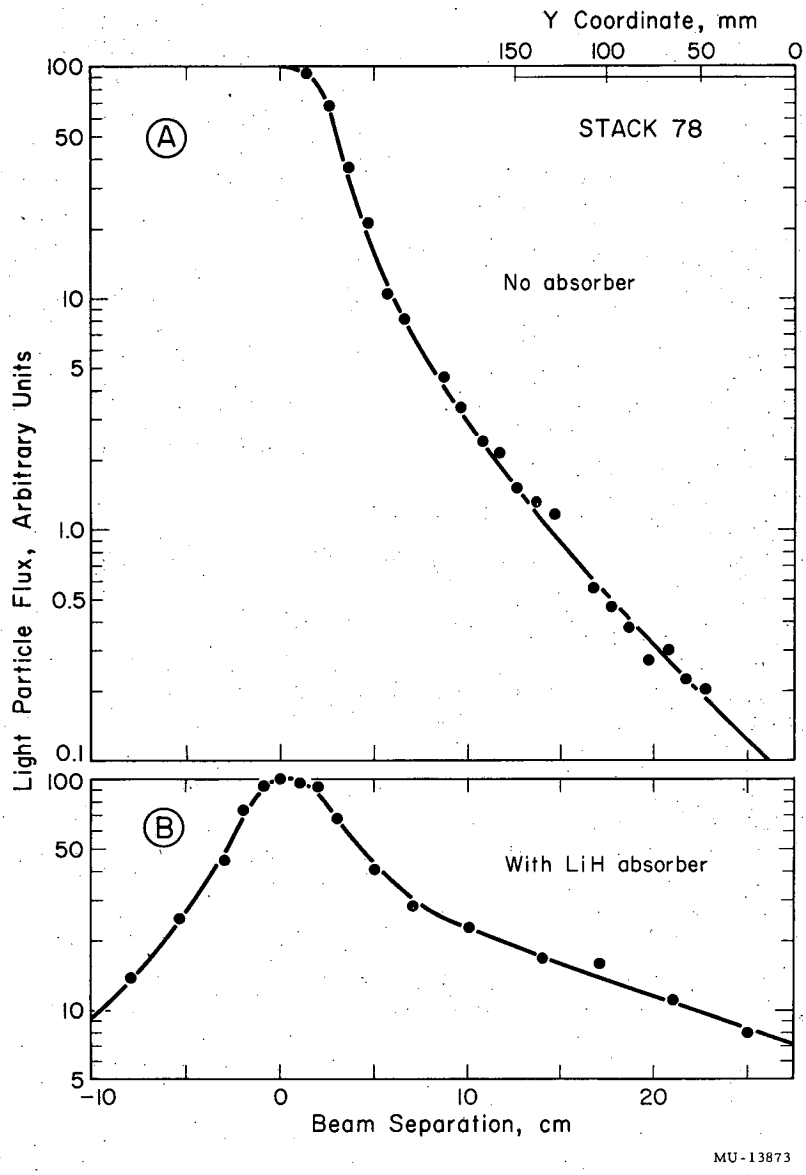

Fig. 5. The light-particle flux (π, μ, and e) in arbitrary units. The curve in Fig. 5A corresponds to the measurement without the lithium hydride absorber in place. The curve in Fig. 5B corresponds to the measurement at the time of the exposure, with 19.8 g/cm^2 (24.9 cm) of lithium hydride absorber in the beam. The flux measurements, carried out with test plates, have been normalized to 100 at the peak. The position of Stack 78 during the exposure and the grid coordinates on the emulsions are also shown.

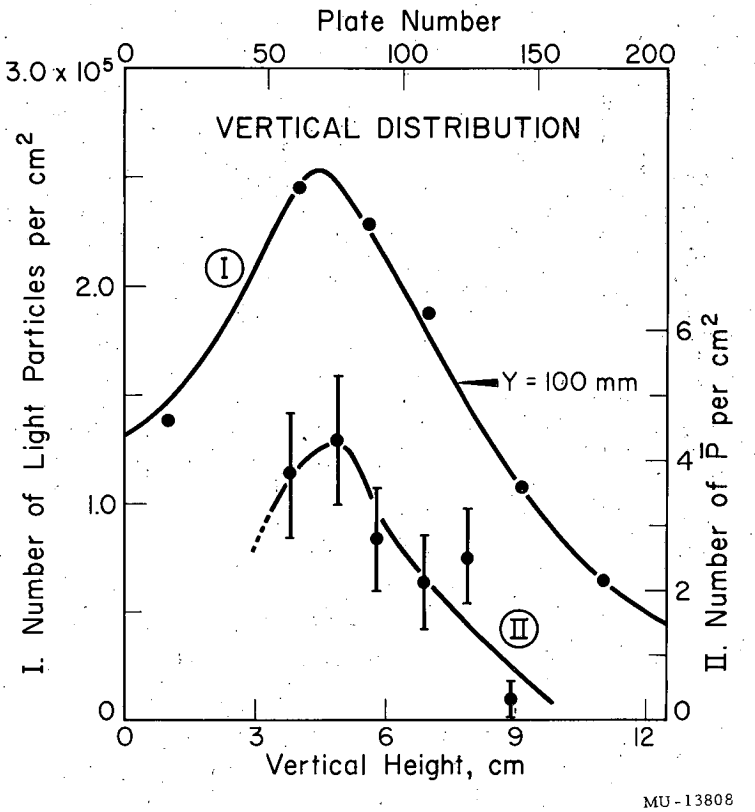

Fig. 6. The vertical beam distribution. Curve 1 gives the light-particle flux as measured at Y coordinate 100 in each plate of the stack. Curve 2 gives the antiproton flux as measured between Y coordinates 80 and 130.

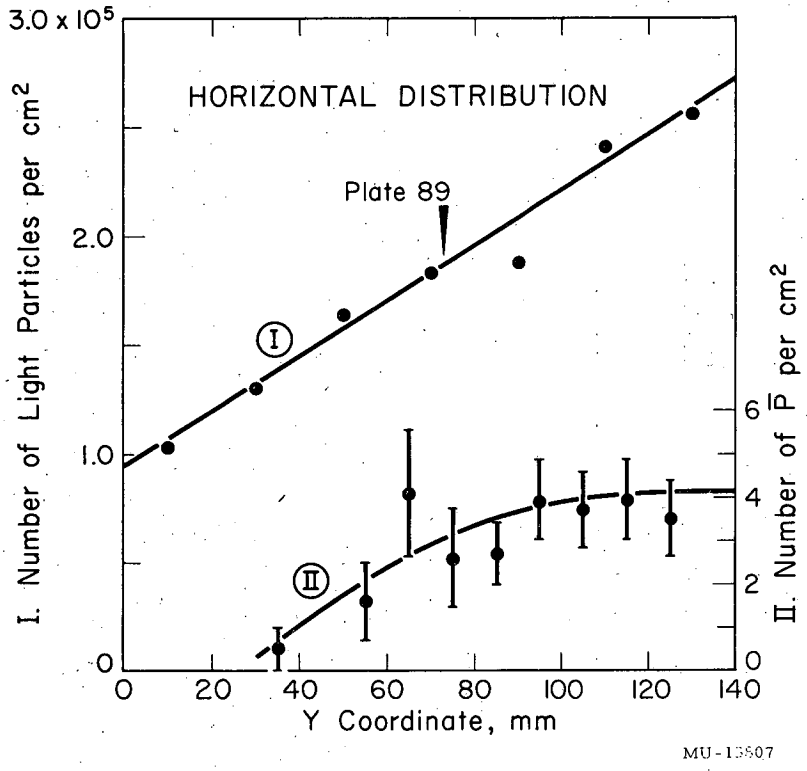

Fig. 7. The horizontal beam distribution. Curve 1 gives the light-particle flux as measured in Plate 89, a plate close to the peak of the vertical distribution. Curve 2 gives the antiproton flux as measured for Plates 50 to 130.

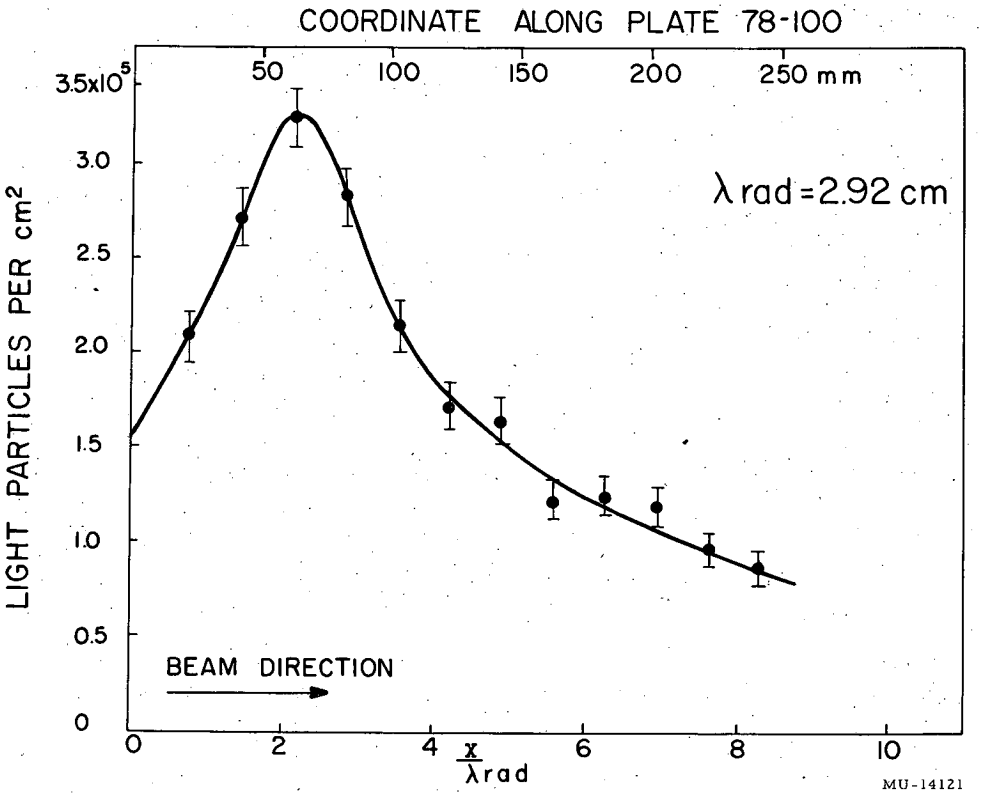

Fig. 8. The transition curve for the light-particle flux. The light-particle flux was measured along the beam direction (the X coordinate along Plate 78-100). The curve is plotted against distance along the plate as measured in radiation lengths in emulsion. The peak at about 2 units of radiation length clearly indicates the presence of a large fraction of electrons in the beam.

The Analysis of Antiproton Stars

Gerson Goldhaber, Theodore Kalogeropoulos, and Rein Silberberg

Of the 130 antiproton stars found in the separated antiproton beam we have analyzed 100 to date. The main features of the antiproton stars are very similar to those previously observed in the "Antiproton Collaboration Experiment."[6] Table III gives the present result in terms of average characteristics of the stars, based on 95 new stars. The pertinent new features in this analysis are as follows.

a. $\bar{p}$-H Scattering

We have observed four events that are due to $\bar{p}$-H scattering. In each case one prong is a positive proton, the other an antiproton that later annihilates. The events were established as $\bar{p}$-H scattering by coplanarity as well as by angular and energy correlation. One additional event was found by Dr. Gösta Ekspong and co-workers of Uppsala.[7] Table IV gives the antiproton energy $T_{\bar{p}}$ and the c.m. scattering angles. The corresponding $\bar{p}$-H scattering cross section is 75^{+50}_{-32} mb.

b. Mean Free Path

The mean free path in the energy interval from 40 to 200 Mev in nuclear emulsions, based on all events known to date, is $\lambda = 17.7$ cm, which gives an annihilation radium $R = r_0 A^{1/3}$, where $r_0 = 1.72 \pm 0.08$ fermis.

c. Cross Section at Low Antiproton Energy

We find some antiprotons interacting at very low energy, $T_{\bar{p}} = 10$ to 25 Mev, which appears to indicate a rise in the cross section with decreasing energy.

d. The π^+/π^- Ratio

A large fraction of the pions from the annihilation stars with energy $T_\pi < 100$ Mev came to rest in the stack. We observe a π^+/π^- ratio for these pions of 0.4 ± 0.13 (that is, 16 π^+ to 40 π^- mesons). Figure 9 shows the two energy spectra and shows that this negative excess cannot be ascribed to the Coulomb effect. The π^+/π^- ratio expected on the basis of isotopic conservation (without consideration of any further restrictions) is 0.73 for the average n/p ratio in emulsion, $\langle n/p \rangle_{\text{emuls}} = 1.2$.

e. The Nuclear Excitation

The very marked difference between the nuclear excitations in stars formed from antiprotons at rest and from antiprotons in flight--as inferred from the total energy in heavy prongs--is corroborated. Figure 10 gives the distribution of ΣE_H. This again confirms our earlier conclusion that the annihilations at rest occur on the nuclear surface.

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[7] A. Gösta Ekspong, Johansson, and Ronne, unpublished results.

Table III

Average values of characteristics of antiproton annihilation stars

	$N\pi^{\pm}$	$\bar{N}_{K0}$	$\bar{N}_{EV}$	$\bar{N}_{H}$	$\Sigma E_{\pi^{\pm}}$	ΣE_{H}	No. stars
At rest	0	1.6	4.8	6.4	0	247	5
In flight	0	3.0	6.5	9.5	0	382	2
Combined	0	2.0	5.3	7.3	0	286	7
At rest	1	1.4	1.5	2.9	289	197	8
In flight	1	2.3	4.7	7.0	389	299	9
Combined	1	1.9	3.2	5.1	342	251	17
At rest	2	1.2	2.4	3.6	626	174	17
In flight	2	1.9	4.6	6.5	634	270	13
Combined	2	1.5	3.4	4.9	629	216	30
At rest	3	0.7	1.9	2.6	932	202	18
In flight	3	1.0	2.5	3.5	1034	150	10
Combined	3	0.8	2.1	2.9	968	111	28
At rest	4	0	1.1	1.1	1224	13.3	7
In flight	4	0.3	0.7	1.0	1197	50	3
Combined	4	0.1	1.0	1.1	1216	633	10
At rest	5	0.5	0.5	1.0	1500	54	2
In flight	5	0	3	3	1164	51	1
Combined	5	0.3	1.3	1.6	1387	105	3
At rest	2.4	0.9	2.1	3.0	724	133	57
In flight	2.2	1.7	3.8	5.5	706	228	38
Combined	2.3	1.2	2.8	4.0	717	171	95

Table IV

Compilation of data for $\bar{p}$ -H scattering events

Event No.	($\bar{p}$) (degrees)	$T\bar{p}$ (lab) (Mev)
3S - 34	17.6	175
3 - 26	33.4	72
6 - 6	44	175
3S - 22	48.5	184
3S -38	50	142

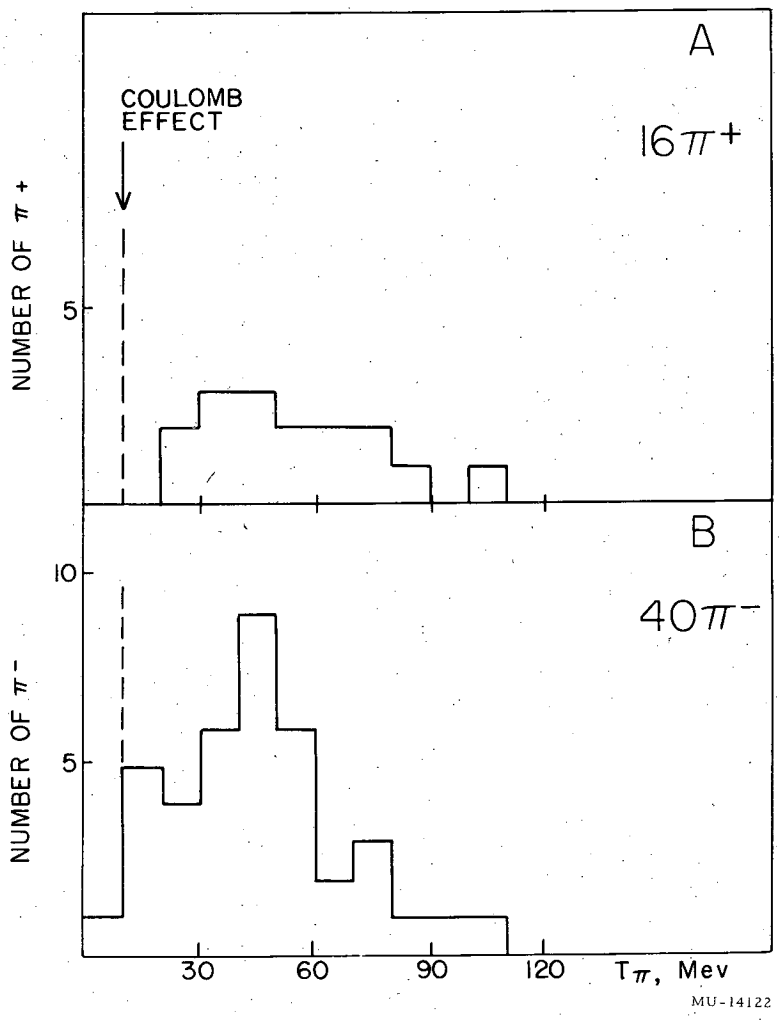

Fig. 9. The π^+ and π^- spectra.

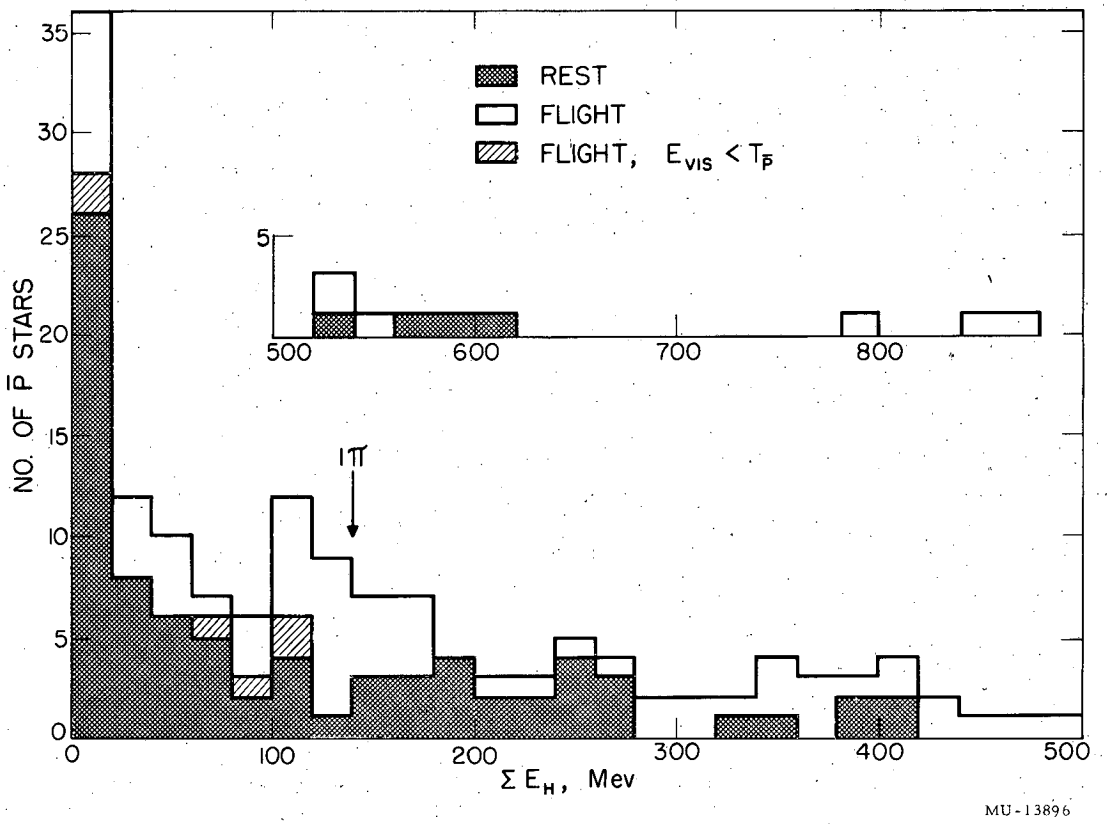

Fig. 10. The distribution of the energy in heavy prongs, ΣE_H. The arrow indicates the expected energy release in heavy charged particles corresponding to the absorption of one pion.

f. The p_ρ Question

As antiproton stars have been observed over a very extensive range of visible energy release, it appears reasonable that one should observe the limiting case of no visible energy release, or p_ρ. The suggestion has also been made by B. M. Pontecorvo[8] and by T. D. Lee,[9] on very different physical grounds, that p_ρ events should be expected for theoretical reasons. The exposure in the separated antiproton beam lends itself well to the study of this question because of the relatively low background of positive protons. Together with 79 antiprotons coming to rest (out of a total of 130 antiprotons), we have observed 7 p_ρ tracks obeying the strict conditions that obtain for all the antiproton tracks. Two of these tracks run near the interface between emulsions. Figure 11 shows a plot of θ_{rel}, the space angle between the track and the general direction of the light particles in the immediate vicinity of the track, versus $|\bar{R} - R|$.

The density of p_ρ endings lying outside the inner rectangle in Fig. 11, which contains all the $\bar{p}$ tracks, can be given as 11/3 = 3.7 inside a rectangle that is four times the unit size, and 19/8 or 2.3 inside a rectangle nine times the unit size. It must be noted that in the outer region-- $\theta_{rel} > 6^\circ$ and $|\bar{R} - R| > 40$ mm--some scanning bias against picking up such tracks is suspected. The comparison is thus between seven p_ρ events (of which two must be eliminated because they occur near the surface) and a density of 3.7 for the region $3^\circ <$, and $|\bar{R}-R| < 40$ mm. The conclusion is thus that if $\bar{p}_\rho$ events exist they do not amount to more than 1% of the antiproton stars. All other p_ρ must be ascribed to a background of positive protons.

g. The Pion Spectrum

The energy for all pions with dip angle $< 20^\circ$ was measured. The result is:

for stars at rest,	$\bar{T}$ = 161 Mev;
for stars in flight,	$\bar{T}$ = 182 Mev;
combined,	$\bar{T}$ = 171 Mev.

[8] B. M. Pontecorvo, Zhur. Eksptl. i Teort. Fiz. 30, 947 (1956), translated in Soviet Physics, JETP 3, 966 (1957).

[9] T. D. Lee, in Proceedings of the Seventh Annual Rochester Conference on High-Energy Physics, 1957 (to be published).

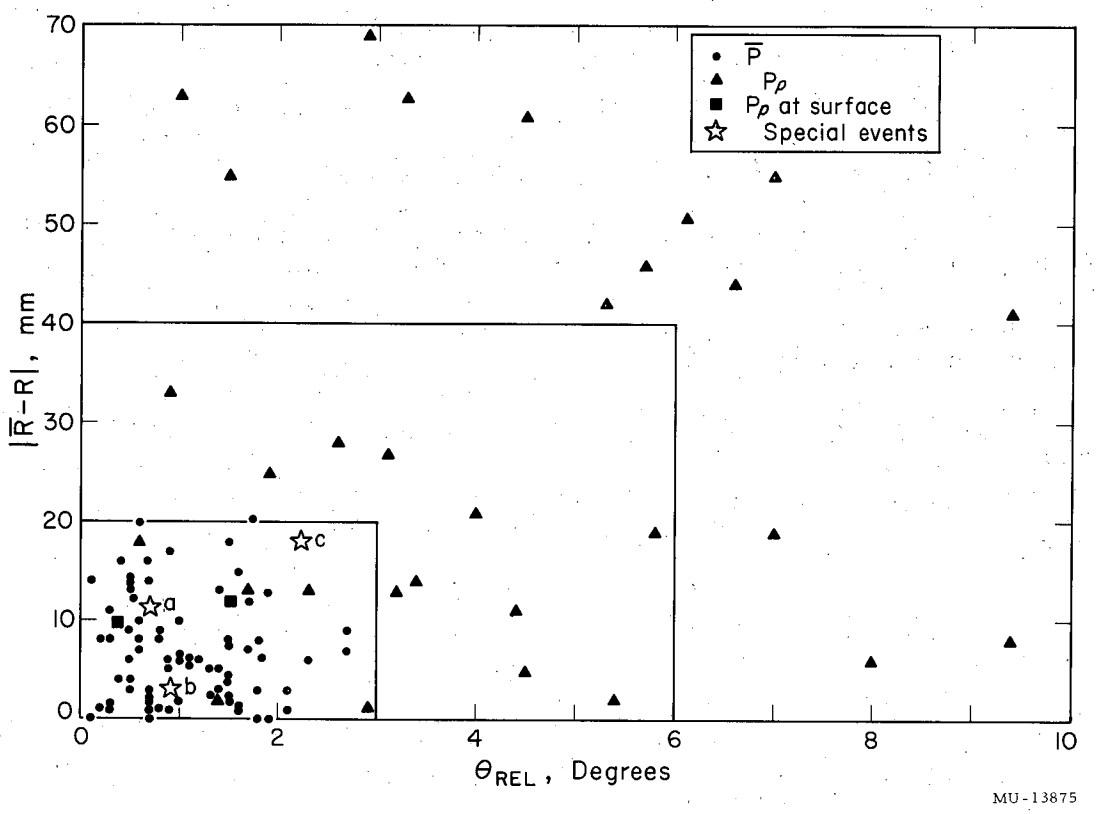

Fig. 11. A plot of the relative entrance angle θ_{rel} versus $\Delta R = |\bar{R}-R|$, the deviation in range from the mean. The region $\theta_{rel} \leq 3^{o}$ and $\Delta R \leq$ 20 mm contains all the antiproton tracks. The special events are (a) a $\bar{p}_\rho$ event with a clear recoil; (b) a $\bar{p}_\rho$ event with an accompanying star $\sim 8\mu$ away from the ending; (c) a $\bar{p}$ star with two short low-energy prongs.

NUCLEON-NUCLEON INTERACTION EXPERIMENTS

Several experiments are being planned and prepared for the 184-inch cyclotron. They concern mainly a continuation of the study of the p-p interaction. They are:

(a) Investigation of the polarization of the protons in P + p-π scattering (Foote);

(b) Polarization correlation experiment in p-p scattering (Larsen);

(c) A study of the polarization tensor of deuterium (Mermod).

EXPERIMENTS ON μ MESONS

We have two experiments planned to find the direction of the polarization of μ mesons with respect to their momentum in π-μ decay.

This information is fundamental importance, and justifies even "long-shot" experiments. They involve

(a) change in stopping properties of magnetized iron at the Bevatron (Steiner);

(b) Coulomb scattering of μ mesons at the 184-inch cyclotron (E. Rogers).

ARC RESEARCH

Chester M. Van Atta in charge

HIGH-VACUUM AND ULTRA-LOW-TEMPERATURE REFRIGERATION

Hugh R. Smith

Material for this section had not been received at the time of publication, but may be expected in a subsequent report.

ACCELERATOR OPERATION AND DEVELOPMENT

BEVATRON

Edward J. Lofgren in charge

A report for May, June, July 1957 is to be issued separately under the title "Bevatron Operation and Development. XIV."

184-INCH CYCLOTRON

Robert L. Thornton in charge

MODIFICATION

James T. Vale

Material for this section had not been received at the time of publication, but may be expected in a subsequent report.

60-INCH CYCLOTRON

W. B. Jones in charge

DEVELOPMENT

Electrical Mechanical Beam-Pattern Indicator

Kenneth Jenkins

Many times it is necessary to accurately know the total beam parameters, so that small targets and defining slits can be accurately located. The positioning of the exit beam from the cyclotron can be accomplished in many ways; none of these ways are well defined. Thus it is necessary to use a trial-and-error system repeatedly taking burn patterns on outdated emulsion plates. A preferable method would be to use a continuous beam-pattern indicating device, such as a flourescent screen and a remote TV camera, but the difficulty with the screen is the small beam level that can be handled by it without burnout.

A solution that we have successfully used is to make a beam-dissecting system along the line of a flying-spot scanning disc, as used in early TV systems.

From a practical standpoint, several difficulties must be overcome, owing to the particular qualities of a CW cyclotron. The major difficulties are:

(a) the taking of patterns inside a magnetic field,
(b) the great extent of modulation of the beam,
(c) the high range of beam density (from very small to very large beams).

The above complicating factors, consistent with the design of the present system, are in addition to the normal limitations of any installation.

The beam area in question is approximately 2-3/4 inches long by 7/8 inch high. This area is scanned by a 10-mil stainless steel foil wound into an 8-inch-diameter drum, with 24 holes, 120 by 25 mils, spaced laterally every 1/8 inch and peripherally every 15°. Thus scanning an area 1.04 inches by 3 inches gives a total of approximately 1000 units. The stainless steel drum can be rotated in the 8000-gauss field, at speeds up to 250 rpm, with a small fractional-hp dc motor. The dc motor is used to vary the speed of the drum, so that periodic 360-cycle modulation of the beam will not repeat itself at the same spot.

Typical beam densities of the 60-inch cyclotron range from peaks of 100 μa per square cm down to peaks of 10 mμa per square cm, for normal alpha-particle, deuteron, and proton beams. Thus, the range of beam through one of the 25-by-120-mil holes would be from 2 μa to 10 mμa, allowing for an intensity ratio of 20:1 over the scanned area. For a minimum peak voltage into an amplifier of 1 millivolt, the input resistance would have to be adjustable up to 100 megohms, then for scanning rates of one field per second, the beam collector and amplifier would have to have

a capacity of 10 μμf. Although a direct beam pickup is possible, an easier method is employed. That is to use an ionization chamber about 1 cm thick, which gives an amplification of more than 10,000. Now the capacity can be up to 1000 μμf, and the resistance 1 megohm, allowing for all electronic equipment to be at the remote position.

Mounted on the rotating drum are 24 evenly spaced shorting contacts, and a single contact. These contacts are used to synchronize the position of the open hole in the foil by charging up two capacitors, and discharging one on each revolution, and the other on each sweep of the hole across the target. The voltages on the two capacitors are applied to the respectively horizontal and vertical plates of an oscilloscope, using a long-persistent screen. The output of the ionization chamber is amplified and applied to the grid of the cathode-ray tube. For qualitative use in adjusting the cyclotron, the intensity modulation is used. When quantitative data are needed, the horizontal and vertical sweeps are switched off, and the beam output is used in its place.

OPERATION

Summary of operations as prepared by P. McWalters for this quarter:

Alpha bombardments	608.1 hr
Proton bombardments	114.2 hr
Deuteron bombardments	180.5 hr
Beryllium bombardments	69.6 hr
Experimental bombardments	36.1 hr
Operational total	1,008.5 hr
Outage time	143.0 hr
Heat Exchanger	102.0 hr
Available time	1,253.5 hr
Shutdown	922.5 hr
Holidays	32.0 hr
	2,208.0 hr

An operating efficiency of 80.5% (87.6%) was maintained throughout this quarterly period.

Heat Exchanger

The 60-inch Cyclotron was shut down for a period of 10 days, so that a new magnet-oil heat exchanger could be installed. The old heat exchanger had a total surface area of 1400 square feet, whereas the new one has only 740 square feet. However, the old one was composed of steel

tubes in steel shells, with aluminum fins on the tubes, and the new one has admiralty metal (naval brass) tubes in steel shells. As our installation uses low-conductivity water pumped through a cooling tower, we found that the steel tubes had been attacked by the aerated demineralized water to such an extent that the over-all heat-transfer coefficient was reduced by a factor of two or more. As a result of this poor heat transfer, we were so hampered in our ability to accelerate ions of a charge-to-mass ratio of less than 1/2 (such as beryllium ions) that we could operate for only a period of an hour or an hour and a half before we were forced to turn the magnet off for cooling. With the new heat exchanger, we have been able to operate continuously without turning off for cooling at all.

HEAVY-ION LINEAR ACCELERATOR

Chester M. Van Atta in charge

OPERATION AND DEVELOPMENT

Edward L. Hubbard

During the period from May 1 to June 10 the accerlerator was operating about one-fourth of the time. Two-thirds of the operating time was used for chemistry bombardments and one-third for studying the operation of the machine and for physics experiments. Oxygen ions were accelerated for the first time on May 7, and the first beam of neon ions was obtained on May 29. At the maximum pulse rate of 2 pulses per second, the average beam current varied from 4×10^{-9} to 5×10^{-8} amp. Loss of one week of operation was caused by a lossy rf seal on a drift-tube stem. The rest of the down time was caused by a wide variety of smaller troubles.

A scheduled shutdown began on June 10 for the following purposes:

1. Increase the pulse rate from 2 pulses per second to 10. Three changes in the rf power supplies were necessary to accomplish this:
   (a) Replace the spark gaps that discharge the pulse lines with ignitrons;
   (b) cool the oil in the transformers for the rectifiers that charge the pulse lines;
   (c) replace the temporary rectifier for charging driver pulse line with a larger one.
2. Install power supply for an additional main rf amplifier.
3. Install an air dryer for the injector room.
4. Clean the corrosion out of the water jackets on the drift-tube stems.
5. Clean and service the cooling tower.
6. Install additional shielding.

During the last week of operation before the shutdown there was considerable trouble from sparking in the injector. Therefore in addition to the jobs listed above, considerable effort has gone into eliminating sources of sparking and corona. It was hoped that during part of the shutdown it would be possible to operate evenings; however, operation was possible only occasionally, primarily because of the sparking trouble in the injector.

LINEAR ACCELERATOR

James Donald Gow in charge

OPERATION

The linear accelerator operated on a normal schedule throughout this quarter. Preparations for the transfer of the machine to the University of Southern California are under way. In this connection, engineering and test work to evaluate possible rf interference with television Channel 11 was begun, and it was found that radiation from the oscillators could be greatly reduced by the application of standard shielding and filtering techniques. Data on Van de Graaff performance as a function of ambient temperature were taken.

In order to stay within the recently lowered personnel radiation tolerances it was necessary to add a timber roof shield over the machine.

The experimental program for obtaining accurate ft values for the short-lived Wigner radioisotopes was completed, as also was the program on high-energy β-ray spectroscopy. The series of runs using the 4-inch hydrogen bubble chamber to determine the energy distribution of neutrons emitted by various elements under 32-Mev proton bombardment is continuing.

SYNCHROTRON

Edwin M. McMillan in charge

RESEARCH PROGRAM

Robert W. Kenney

During the period May, June, and July, the synchrotron ran extremely well. The full-energy beam intensity was pushed to 2×10^9 electrons per pulse, and the machine was operated at peak energies down to 50 Mev with excellent stability of both beam intensity and photon pulse shape. Some effort was placed on machine development, particularly on new injection techniques. These points are covered in the operations section of this report.

Robert Cence continued the development of the counting system for selecting photons of a given energy from the bremsstrahlung spectrum.

Robert Kenney, Victor Perez-Mendez, Edward Knapp, and Walton Perkins have measured the ratio of positive photopion yields from deuterium and hydrogen at six (laboratory) pion energies from 45 Mev to 140 Mev and at lab-system angles of 20°, 40°, and 60°. The data have been compared with the Chew and Lewis theory for the ratio, and information has been obtained on the proton spin-flip probability in photopion production in hydrogen.

A gradual transition is observed from complete spin flip at low energy to a mixture of spin flip and no spin flip at the higher energies. A more complete theory by Chew is now being evaluated numerically so that more dependable spin-flip probabilities can be calculated.

John Atkinson and Victor Perez-Mendez checked out a new gas Cerenkov counter on relativistic electrons. The counter is one member of a counter telescope that is in use at the Bevatron for measuring σ_a and σ_T for high-energy neutrons on various nuclei.

John Caris, Robert Kenney, Edward Knapp, Victor Perez-Mendez, and Walton Perkins have calibrated photon-counting efficiency of a gamma-ray telescope. The telescope will be used in the near future for observing the reaction $\pi^+ + p \rightarrow \pi^+ + p + \pi^o$ at cyclotron pion energies. The counter calibration employed the photon difference method for obtaining calibration points from the 25-Mev threshold to 300 Mev. The procedure was an elaborate one which required that the synchrotron run at several energies from 50 Mev to full energy with reasonable stability in beam intensity and photon pulse shape. This procedure placed very stringent requirements upon the operation of the synchrotron, and the machine behaved very satisfactorily.

OPERATIONS

Rudin M. Johnson

The synchrotron was used primarily for physics research experiments. The maximum beam intensity during the first part of May was 10^9 electrons per pulse at 340 Mev peak energy.

An attempt was made to improve the beam intensity during the last week in May. A second injector gun was arranged on the west side of the synchrotron. Electrons were injected from the east and west guns together. This additional injection gave no increase in accelerated beam; instead, its effect reduced the beam intensity. A beam of medium intensity was accelerated from the west gun alone by recompensating the magnet.

At this time we also tried injecting with a longer injector pulse (4 μsec instead of 2 μsec). This long pulse was then shaped to give a condition for acceptance. (The pulse voltage began at 70 kv and ended at 120 kv.) This method of injection doubled the beam intensity. More time is needed to determine whether the injector pulse shape or just higher voltage contributed to this beam increase.

During June and July the beam intensity has been kept low for the physics experiments by Cence and Caris.

During June another attempt was made at double injection. We found that the injector pulse on the second gun with no emission from the filament reduced the beam injected from the first gun. A coaxial gun is being designed that will have a minimum perturbation field.

During Caris's run the peak γ-ray energy was varied over six different values, and remained accurate within the limits indicated below.

340 Mev ± 3 Mev
250 Mev ± 1 Mev
200 Mev ± 1 Mev
150 Mev ± 3 Mev
100 Mev ± 4 Mev
50 Mev ± 4.5 Mev

The beam was stable even at low energies, and these settings could be reproduced with ease.

Construction of the Linac No. 2 vault and Bldg. 68 mezzanine has been under way during this period, and is now nearing completion.

While we were waiting for the vault construction, the Linac No. 2 was operated for a short period for Graham Welch and Paul Flanders of Dr. Tobias's group. Their experiment was penumbra measurements of γ rays from a copper target and lead collimator on a film-and-lucite-stack target.

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