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Ernest O. Lawrence Radiation Laboratory

PHYSICS DIVISION SEMIANNUAL REPORT
November 1960 through April 1961

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Lawrence Radiation Laboratory
University of California
Berkeley, California

May 1961

GENERAL PHYSICS RESEARCH

PHYSICS RESEARCH

Luis W. Alvarez in charge

LIQUID HYDROGEN BUBBLE CHAMBERS

Operation and Development

James Donald Gow

72-Inch Chamber

Operation of the 72-inch chamber on the associated-production experiment has continued throughout this report period. The chamber was shut down for 6 weeks in December and January to permit the installation of a thin re-entrant beam window. This was required to reduce the Landau effect in the window and invisible hydrogen so that beams with 0.1% momentum spread at 1 Bev can effectively be utilized.

After engineering analysis and a substantial proof-testing program, a stainless steel window of 2X6-in. apertures and 0.030-in. thickness was installed. The angle of the window was chosen to permit photography of the track up to the surface of the window.

During this shutdown the centrifugal liquid-vapor separator was removed from the expansion line. This modification increased the rate of pressure change on expansion and recompression with a resultant decrease in refrigeration requirement to one-half that needed previously. This in turn decreased the thermal gradients and optical turbulence markedly. Operation at lower temperature and pressure is now possible, and the normal vapor pressure is maintained at 68 psig.

The 72-inch chamber was successfully operated on deuterium for a part of the report period. A television chamber-viewing system has been brought into operation. The system stores the tracks between expansions and is erased automatically just prior to expansion. This installation has proven very valuable for chamber and beam adjustment and monitoring.

More than one million pictures have been taken during the present associated-production run. This experiment, scheduled to end on June 1, will have run for 13 months.

15-Inch Chamber

The 15-inch K^- and antiproton run was completed in February. Since no further research runs are scheduled for this instrument prior to the major Bevatron shutdown, the chamber has been placed in storage.

25-Inch Chamber

The construction schedule for this chamber has been delayed, with the intent of making it available after completion of the major Bevatron modification program. Design work has proceeded and detailing is nearly complete on the magnet. The internal thermal shields, chamber body, and expansion mechanism are now under design. A hydraulic expansion system with a sinusoidal action, utilizing a gas-filled cylinder for energy storage, has been designed. An IBM 650 program has been written and used to predict the system performance.

Several methods of illumination are being investigated theoretically and model work will be undertaken. The possibility of operation with helium as well as with hydrogen or deuterium is under study. A film format compatible with existing 72-inch data-analysis equipment has been adopted.

Bubble Chamber Development

In addition to the design work for the 25-inch chamber described above the development program has included a small effort on superconducting magnet studies. The recent discovery of the high critical field and current density possible with Nb_3Sn makes it appear likely that substantial advances in experimental technique or economic savings can result from practical applications of superconducting electromagnets.

Wire samples have been prepared, which exhibited the desired properties, by using the Bell Laboratories prescription and modification thereof. Tests on these samples indicated critical fields greater than 150 kilogauss. A small solenoid was wound and successfully operated in a 24-kilogauss field, of which 20 kG was supplied by an external normal magnet. The design of a 30- to 50-kG solenoid is in progress.

Data Reduction

Margaret Alston and James Donald Gow

During the past 6 months the data-reduction group has been analyzing pictures from the 72-inch chamber antiproton and associated-production experiments, and the 15-inch chamber K^--p, K^--d, and $\bar{p}$-p experiments. The average number of scanners working in the group during this period has been 48.6 full-time equivalents.

In the 72-inch chamber data-reduction system there are now 10 scanning projectors and two measuring projectors (MP IIA and B) in operation in Building 50. One scanning projector is being used by the bubble chamber

crew for film quality monitoring. Three scanning projectors are on loan to Wisconsin University and one each to Johns Hopkins University and Duke University. At Berkeley about 320,000 pictures have been scanned and 16,000 events measured in the 6-month period. Two more measuring projectors (MP IIC and D) are nearing completion. The output of the system is being limited by the available scanning personnel.

In the 15-inch chamber system there are five scanning projectors being used by the Alvarez-Gow group, two by the Goldhaber group, one by the Cork group, and one by the Leitner group at Syracuse. There are two measuring projectors in operation; one is used full time by the Alvarez-Gow group and the other is shared by the Alvarez-Gow and Goldhaber groups. Personnel of the Alvarez-Gow groups have scanned about 240,000 pictures, and 24,000 events have been measured. A third measuring projector is nearly ready and should be operational within a month.

Work is proceeding toward further automation of the 72-inch chamber measuring projectors. In this new system an IBM card is punched for each event by the scanning technician at the scanning projector. This card contains both the identification of the event and the positions of its vertices, and also any additional interesting physics information. The card is subsequently used to make a master list of the events in an experiment. It can also be read by the measuring projector, and controls the sequence of measuring operations, thus making measuring more automatic and reducing errors. One scanning projector has been modified so that punched cards can be made, and the measuring projector MP IIB has been modified to read the cards and operate in the automatic mode. A few test events have been measured with great success. Work is now in process to modify six scanning tables for use during the next 72-inch chamber experiment, and to complete the modifications to MP IIB, including an automatic film advance and frame-finding device. The two measuring projectors under construction (MPII C and D) will operate on the new system. The PANG computer program is being modified to accept data from the measurement of all tracks in all views and to perform the necessary track-pairing and selection operations prior to computation.

Library routines are being written to make master lists on magnetic tape from the scan cards, and subsequently to keep a record of the status of each event during its analysis. These library programs should make the handling of high-statistics experiments easier.

Work has continued on the spiral reader. The programs are now complete and the machine is designed. Some parts have already been fabricated and others are under construction. It is hoped that the machine will start measuring events about July. This machine will be used for measuring simple two- and four-prong events on 72-inch chamber film.

A small group under the direction of Luis Alvarez has been working on the design and construction of the prototype for a combined scanning and measuring projector. Ultimately the machine will probably be connected directly to a 7090 computer. This would allow measurements and the fitting of the data as soon as an event is found. In this way the measurer would know immediately whether the event required remeasurement or special treatment. This type of system would be of great value for the analysis of unusual events.

Studies in progress are intended to define the relative operational and economic merit of several high-volume event-analysis systems. By late summer either one system or a combination of such systems will be selected and prototype development will begin.

Interaction Studies

K^- - p Interactions

The experiments begun during the summer of 1960 to study the K^- - p interactions from 0 to 850 Mev/c with the 15-inch hydrogen bubble chamber were continued through January 1961.

The number of interactions in the low-momentum region $p < 300$ Mev/c has been tripled since previously reported data.[1] One beta decay of Σ^- has been observed,[2] yielding a decay rate lower by at least an order of magnitude than the predictions by Feynman and Gell-Mann.

Analysis of the low-energy K^- - p exposures made in 1958 is nearing completion. All interactions within a specified fiducial volume have been processed by the 704-709 programs PANG, KICK, and EXAMIN, and the results are on summary library tapes. Determination of final numbers for at-rest hyperon production ratios, cross sections as a function of K^- lab momentum, and hyperon lifetimes is in progress.[3]

Exposures were made at 300, 350, 390, 440, and 520 Mev/c to investigate in detail the anomalous behavior of the K^- - p interaction in the vicinity of 400 Mev/c. About 4000 events have been measured to date. At 390 Mev/c the elastic and charge-exchange differential cross sections are consistent with $1 + 3 \cos^2 \theta$, with an indication of a slight forward peaking. The production of Σ^+ predominates over Σ^-, a reversal from the lower-energy behavior in these channels. Strong $\cos\theta$ and $\cos^2\theta$ are observed in the Σ^+ angular distribution, whereas the Σ^- production is nearly isotropic. The Λ 2π channel is strongly enhanced in this momentum region.

At 640, 760, and 850 Mev/c, 2000 cases of $\Sigma^+ + \pi^-$ and $\Sigma^- + \pi^+$ production have been measured. The Σ^+ angular distribution is strongly peaked forward at 640 Mev/c, isotropic at 760 Mev/c, and strongly peaked backward at 850 Mev/c. The Σ^- angular distribution, on the other hand, has very large $\cos^2 \theta$ terms, especially at the lower two momenta.

---

[1] Luis W. Alvarez, The Interactions of Strange Particles, Report to 1959 Kiev Conference (UCRL-9354, Aug. 1960).

[2] William E. Humphrey, Janos Kirz, Arthur H. Rosenfeld, J. Leitner, and Y.I. Rhee, Evidence for Low Rates for β Decay of Σ^- and Λ Hyperons, UCRL-9605, March 1961.

[3] Ronald R. Ross, Elastic and Charge-Exchange Scattering of K^- Mesons in Hydrogen (Thesis), UCRL-9749, (June 1961); and William E. Humphrey, Hyperon Production by K^- Mesons Incident on Hydrogen (Thesis), UCRL-9752, (June 1961).

All $\Lambda\pi^+\pi^-$ have been measured. Clear evidence for $Y^{*\pm}$ production is found at 760 and 850 Mev/c, where 243 and 128 cases respectively are observed corresponding to production cross sections of 2.4 mb and 1.9 mb.[4] Nonresonant $\Lambda\pi^+\pi^-$ background at these momenta are 0.6 mb and 1.0 mb. An Adair analysis of those Y^* produced at forward and backward angles with respect to the incident K^- was made in order to establish the spin of Y^*. The decay angular distribution shows no $\cos^2\theta$ term characteristic of the decay of a spin-3/2 particle. However, a strong $\cos\theta$ term does appear. This term has been satisfactorily explained to be a consequence of Bose statistics between the two final-state pions.[5] Inclusion of the Bose statistics effect obscures the Adair analysis to the extent that no definitive statement can be made as to the spin of Y^* on the basis of the 760- and 850-Mev/c data. Further experiments at higher momenta are being planned with the 72-inch chamber, and it is hoped that a clear answer as to the spin of Y^* will be obtained from these experiments.

Y^* polarization was searched for at all momenta. Only at one momentum was a statistically significant Λ decay asymmetry observed. The analysis of this asymmetry on the basis of a spin-1/2 Y^* suggests that the Y^* decays into a $\Lambda\pi$ in the S state. This is the parity assignment which is consistent with the experimentally favored Kp Λ parity and the association of Y^* with the Dalitz-Tuan resonance.

Very few decays of Y^* into $\Sigma\pi$ have been observed. The branching ratio $\Sigma\pi/\Lambda\pi$ is found to be $2 \pm 2\%$.[6] This is somewhat lower than global symmetry would predict for a spin-3/2 Y^* or the Dalitz-Tuan resonance would predict for spin-1/2 Y^*, but not inconsistent with either.

Analysis of the data obtained in the 15-inch hydrogen bubble chamber during an earlier exposure at 1.15 Bev/c has continued. A study of the reaction

$$K^- + p \rightarrow \bar{K}^0 + \pi^- + p \qquad (1)$$

has resulted in the discovery of a resonance in the $\bar{K}^0\pi^-$ system at an energy of 885 ± 3 Mev, with a full width at half maximum (Γ) of 16 Mev.[7] Comparison of Reaction (1) with the reactions

$$K^- + p \rightarrow K^- + \pi^+ + n \qquad (2)$$

and

$$K^- + p \rightarrow K^- + \pi^0 + p \qquad (3)$$

---

[4] Margaret H. Alston and Massimiliano Ferro-Luzzi, Pion-Hydrogen Resonances, Revs. Mod. Phys. (in press) (UCRL-9587, March 1961).
J. P. Berge, Pierre Bastien, O. Dahl, Massimiliano Ferro-Luzzi, Janos Kirz, D. H. Miller, J. J. Murray, Arthur H. Rosenfeld, Robert D. Tripp, and M. B. Watson, Phys. Rev. Letters 6, 557 (1961).

[5] R. H. Dalitz and Donald H. Miller, Phys. Rev. Letters 6, 562 (1961).

[6] Pierre Bastien, Massimiliano Ferro-Luzzi, and Arthur H. Rosenfeld, Sigma Decay Modes of Pion-Hyperon Resonances, Phys. Rev. Letters (in press).

[7] Margaret H. Alston, Luis W. Alvarez, Philippe Eberhard, Myron L. Good, William Graziano, Harold K. Ticho, and Stanley G. Wojcicki, Phys. Rev. Letters 6, 300 (1961).

has shown that a resonance in the $K^- - \pi^+$ system also exists and that the $(\bar{K}\pi)$ resonance, called K^*, has an isotopic spin of 1/2.

To obtain the Σ/Λ branching ratio of the Y^* with isotopic spin 1, called Y_1^*, (already reported[8]), the following reactions were analyzed:

$$K^- + p \rightarrow \Sigma^+ + \pi^- + \pi^0 , \quad (4)$$

$$K^- + p \rightarrow \Sigma^- + \pi^+ + \pi^0 , \quad (5)$$

$$K^- + p \rightarrow \Sigma^0 + \pi^+ + \pi^- . \quad (6)$$

The branching ratio was found to be less than 8%, and consistent with zero.[9] These results are consistent with those reported in Ref. 6.

A study of the reactions

$$K^- + p \rightarrow \Sigma^+ + \pi^- + \pi^+ + \pi^- , \quad (7)$$

$$K^- + p \rightarrow \Sigma^- + \pi^+ + \pi^+ + \pi^- , \quad (8)$$

$$K^- + p \rightarrow \Sigma^0 + \pi^0 + \pi^+ + \pi^- \quad (9)$$

has shown that there is probably a resonance in the $(\Sigma\pi)$ system with a mass of about 1405 Mev and full width (Γ) of about 20 Mev.[10] This resonance, called Y_0^*, has isotopic spin zero. Further evidence for this resonance has subsequently been found at lower momenta.[6]

K^- - d Interactions

A systematic study of the momentum correlation in 282 events of the type $K^- + d \rightarrow \Lambda + \pi^- + p$ has shown the presence of three distinct reaction sequences, i.e.,

(a) $K^- + d \rightarrow \Lambda + \pi^- + p$,

(b) $K^- + d \rightarrow (\Sigma^+ + N) + \pi^- \rightarrow \Lambda + \pi^- + p$,

(c) $K^- + d \rightarrow Y^{*-} + p \rightarrow \Lambda + \pi^- + p$.

---

[8] Margaret Alston, Luis W. Alvarez, Philippe Eberhard, Myron L. Good, William Graziano, Harold K. Ticho, and Stanley G. Wojcicki, Phys. Rev. Letters 5, 520 (1960).

[9] Ibid., Phys. Rev. Letters (in press) (UCRL-9675).

[10] Ibid., Phys. Rev. Letters (in press) (UCRL-9686).

Among the events investigated, the relative frequencies for these reactions were 87:102:93. Although sequence (c) constitutes a large fraction of the Λ-π^--p events, it accounts for only 6% of the total K^--d absorption process. By charge independence, an additional 3% of the absorptions proceed via $K^- + d \rightarrow Y^{*0} + n \rightarrow \Lambda + \pi^0 + n$.

The production of the Y-π resonant state in deuterium permits an independent measurement of the Σ/Λ branching ratio in Y^* decay. We have examined 140 events of the type $K^- + d \rightarrow \Sigma^- + \pi^0 + p$ obtained in a group of 8000 K^- - d absorptions. The number of events with T_p in the region expected for Y^* production indicates $(Y^{*-} \rightarrow \Sigma^0 + \pi^-)/(Y^{*-} \rightarrow \Lambda + \pi^-) < 6 \pm 2\%$.

$\bar{p}$-p Interactions

The following results have been obtained in the continuing analysis of the interactions of 1.61-Bev/c antiprotons in the 72-inch hydrogen bubble chamber. On the basis of 20 events that fit the reaction $\bar{p} + p \rightarrow \pi^+ + \pi^-$ and 11 events that fit $\bar{p} + p \rightarrow K^+ + K^-$, the cross sections for these reactions are determined to be 100 ± 25 μb and 55 ± 18 μb respectively. The cross sections for the reactions $p + p \rightarrow p + p + \pi^0$ and $p + p \rightarrow p + n + \pi^+$ have been measured as $1.6 \pm .3$ mb and $1.16 \pm .3$ mb respectively, and the total inelastic nonannihilation cross section is estimated to be 5.3 mb, leaving 51 ± 3 mb for the annihilation cross section. The fractions of annihilations resulting in events with 2, 4, 6, or 8 charged pions are consistent with the predictions of the Fermi statistical model with an interaction volume of $(4.8 \pm .3)\,\Omega_0$,[1] where $\Omega_0 = (4\pi/3)(\hbar/m_\pi C)^3$. These results are to be published in July.

A measurement of about 4,000 $\bar{p}$-p annihilations at 1.61 Bev/c into four prongs is under way, with the object to study the annihilation mechanism and the pion correlations by examining the angular and momenta distributions, the angular correlation, the effective masses of pion doublets and triplets of different charge combinations, and the missing masses.

Preliminary results based on 2000 measured events are obtained only for the angular distributions in respect to the $\bar{p}$ beam direction; they show a tendency for negative pions to go forward and positive pions to go backward. Five hundred have been identified as $\bar{p} + p \rightarrow 2\pi^+ + 2\pi^-$ and $\rightarrow 2\pi^+ + 2\pi^- + \pi^0$; for these, the distribution of negative pions combined with the reflected distribution of positive pions can be expressed by $1 + A\cos\theta + B\cos^2\theta$, where $A = 0.25 \pm .08$ and $B = 0.415 \pm .12$. Possible biases have not been eliminated from these data.

A study of K-meson production in antiproton-proton annihilation was performed in the 72-inch liquid hydrogen bubble chamber at 1.61 Bev/c and 1.99 Bev/c.[2] A final sample of 287 $K\bar{K}n\pi$ annihilation events was analyzed. The data were compared with the Fermi statistical model. The multiplicity distribution for all pion annihilation in this and other experiments agrees

[1] Gerald R. Lynch, Final States of the Proton-Antiproton System, Revs. Modern Phys. (in press).

[2] George R. Kalbfleisch, A Study of K Mesons in Antiproton-Proton Annihilation (thesis), UCRL-9597, March 7, 1961.

with a Fermi statistical model using a volume $\Omega_\pi = 5.6 \pm .6\ \Omega_0 = (1.78 \pm .07)^3 \Omega_0$. This value of Ω_π predicts pion multiplicities associated with a K-$\bar{K}$ pair in agreement with the experimental values (2.4 ± .1 pions are associated with a $K\bar{K}$ pair at 1.61 Bev/c). The fraction of the annihilation yielding $K\bar{K}n\pi$ final states is 0.103 ± .011 at 1.61 Bev/c. This fraction indicates a K-meson volume $\Omega_K = (0.12 \pm 0.015)\,\Omega_\pi$. The momentum spectra of the K and π mesons and the angular distributions between pairs of particles in the $\bar{p}$-p center-of-mass system are consistent with phase space. The angular distributions of the K and π mesons relative to the antiproton deviate from isotropy. The distribution in mass of $K\bar{K}$ pairs is consistent with phase space. However, the distribution in mass of $K\pi$ (or $\bar{K}\pi$) pairs deviates from phase space. The deviations are consistent with the recently discovered $K\pi$ resonant state ($\bar{K}^*$) and its charge conjugate.

Pion-Pion Interaction

An experiment is being carried out in the 72-inch hydrogen bubble chamber using 1.03-Bev/c and 1.275-Bev/c π^- and π^+ film obtained in the 1960-61 associated-production run. The reactions looked at are

$$\pi^- + p \rightarrow \pi^- + \pi^0 + p\,, \qquad \text{(a)}$$
$$\pi^+ + p \rightarrow \pi^+ + \pi^0 + p\,. \qquad \text{(b)} \qquad (1)$$

All together, 1275 (1a) events and 450 (1b) events at 1.03 Bev/c have been analyzed and a pion-pion resonance found at $w^2 = 22\ p^2$ ($w = \pi\pi$ energy, c.m.) using the Chew-Low[1] extrapolation procedure. The height of the resonance suggests it is P wave.[2] The angular distribution of the resonance is statistics-limited; however, it is also consistent with P wave.[3] This resonance has since been observed by other workers.[4] Five hundred events at 1.275 Bev/c have been found so far. An analysis at this energy should allow investigation of all pion-pion energies up to $w^2 = 30\ p^2$.

Cusps in Associated Production

The two thresholds for $\pi^- + p \rightarrow \Sigma^- + K^+$ and $\Sigma^0 K^0$ have been resolved, through kinematics and the cross section's threshold dependence.

---

[1] Geoffrey F. Chew and F.E. Low, Phys. Rev. 113, 1640 (1959).

[2] Jerry A. Anderson, Vo X. Bang, Philip G. Burke, D. Duane Carmony, and Norbert Schmitz, Phys. Rev. Letters 6, 365 (1961); and J.A. Anderson, Vo X. Bang, Philip G. Burke, D. Duane Carmony, and Norbert Schmitz, Revs. Modern Phys. July 1961.

[3] D. Duane Carmony, Norbert Schmitz, and R. van de Walle, Bull. Am. Phys. Soc. 6, No. 3 (1961).

[4] A.R. Erwin, R.H. March, W.D. Walker, E. West, D. Stonesill, C. Baltay, H. Courant, W. Ficklinger, E. Fouler, H. Kraysill, J. Sandweiss, J. Sanford, and H. Toft; D.K. Robinson, B. Munir, E. Pickup, and E.O. Salant, Bull. Am. Phys. Soc. 6, No. 3 (1961).

The preliminary value for the mass difference is $M_{\Sigma^-} + M_{K^+} - (M_{\Sigma^0} + M_{K^0}) = 2.2 \pm .5$ Mev.

It should now be possible to look for the cusp in Σ^0 production at Σ^- threshold. The cusp should be present if K^0 and K^+ have the same parity.

The threshold dependence of the $\Sigma^- - K^+$ and $\Sigma^0 - K^0$ cross sections are consistent with pure S wave.

The "noncusp" part of the $\pi^- + p \rightarrow \Lambda + K^0$ cross section, near ΣK threshold, definitely needs $(\cos\theta)^3$, showing the presence of at least P waves.

Charge Symmetry in Associated Production

A test of the charge symmetry of the K^+ and K^0 mesons has been made by comparing the reactions

$$\text{(a)} \quad \pi^+ + d \rightarrow p + \Lambda \text{ (or } \Sigma^0\text{)} + K^+$$

$$\text{(b)} \quad \pi^- + d \rightarrow n + \Lambda \text{ (or } \Sigma^0\text{)} + K^0 .$$

Beams of positive and negative pions at 1.23 Bev/c were directed into the 72-inch bubble chamber filled with liquid deuterium. About 140 events in the π^+ film and approximately three times that many in the π^- film have been measured. The cross sections for Processes (a) and (b) were found to be the same within 20%. Distributions in momentum and angle of the lambdas and of the K mesons, and also lambda-decay asymmetries, have been compared. No large deviations from charge symmetry have been observed. The analysis of the experiment was done in cooperation with workers at Duke University and Johns Hopkins University.

Hyperon Scattering

A study of Λp interactions is being made by using associated-production events from the 72-inch chamber in which a K^0 is subsequently observed to decay. The accompanying Λ has a momentum ranging from 500 Mev/c to 1000 Mev/c. Seven cases of Λ-p elastic scattering have been identified, yielding a cross section of roughly 15 mb. A search is also being made for inelastic scatterings in which a Σ hyperon is produced. Approximately 1/3 of the film has so far been analyzed.

PHYSICS RESEARCH

Walter H. Barkas in Charge

STRANGE-PARTICLE RESEARCH

Walter H. Barkas, John N. Dyer, Norris A. Nickols, Jack Patrick, and Frances M. Smith

Σ Hyperon and Pion Spectra from K^- Interactions at Rest

A total of 2738 K^- stars at rest which displayed no visible strangeness were investigated. Of these, about 580 produced a pion. Some 150 particles observed to be ionizing less than twice the minimum were rejected as being too steep (the inclination to the plane of the emulsion was greater than 30 deg). Another 80 of the particles left the emulsion stack or interacted in flight. These tracks are being multiply scattered and blob-counted to determine the momentum of the pion. The remaining 350 ranges were measured, and the momentum and energy determined.

The pion spectrum derived from these measurements is now under investigation for biases.

Ranges of 165 Σ^+ hyperons and 225 Σ^- hyperons from K^- interactions have been measured. Their pion partners (when such were found) have been treated similarly. Information of this sort is being collected for study of the possibility that the Y^* resonance plays an important part in the K^--capture process. Further data for this study are to be provided by a new stack, the "C" stack, of K.5 emulsion now being analyzed.

"C" Stack Exposure

A stack of 360 9X9-inch 600-micron pellicles of Ilford K.5 emulsion was exposed to the Murray 760-Mev/c separated K^-- meson beam. Preliminary analysis of this stack indicates that approximately 60,000 K^- mesons came to rest in a volume such that all charged pions from the processes $K^- + p \rightarrow \Sigma^{\pm} + \pi^{\mp}$ and $\Sigma^{\pm} \rightarrow \pi$ + nucleon will stop in the emulsion.

The stack will provide events for the further study of the previously reported anomaly in the reaction $K^- + p \rightarrow \Sigma^- + \pi^+$, for study of the capture of K^- mesons in complex nuclei, and for analysis of the hyperfragment production process.

MULTIPLE PION PRODUCTION AT Bev ENERGIES AND LIFETIME OF THE π^0 MESON

Walter H. Barkas, Hla Shwe, and Frances M. Smith

We are continuing our study of interactions of 3.5-Bev and 16-Bev π^- mesons in Ilford K.5 emulsion. The stars are being analyzed for the angular and energy distributions of the multiply produced pions. Further, the stars are being measured to determine the existence of possible Dalitz pairs.

From the distribution of distances from the star to the vertex of the pair (gaps) and from the momentum distribution of the pions one can obtain a value for the mean life of the π^0 meson. In a few cases the total momentum of the pair can be obtained from multiple scattering. Thus the time of flight of the π^0 is determined directly.

To date we have looked at about 1500 interactions of 3.5-Bev π^- mesons. Of these stars, 350 were selected for careful measurement (more than one minimum track present). Thirty measurable gaps were found in 200 measurements.

The data for the gap measurements were taken on a digitized Koristka MS2. The data are punched out on IBM cards directly through the encoder and an electronic translator feeding a card-punch machine (IBM 026). The IBM 650 is programmed to determine from the data cards the presence (and lengths) of gaps.

MUON SCATTERING

Norris A. Nickols and Walter H. Barkas

Analysis of the multiple scattering of 2-Bev/c muons in iron is nearing completion. The observed projected angular distribution after traversal of the 18-inch iron scatterer is being compared to that computed by the Rainwater-Cooper method, and to one computed by a tedious numerical integration of the Snyder and Scott equation, using a single-scattering law obtained from the Born approximation and a Stanford nuclear form factor.

GRAIN DENSITY OF EMULSION TRACKS

Jack W. Patrick and Walter H. Barkas

Extensive measurements were made on the tracks of electrons, pions, mesons, protons, Σ hyperson, and α particles in many samples of emulsion. The measurements were made by using different methods and employing different observers. The results were in good agreement.

The resultant grain density was decomposed into primary and secondary components. Secondary grains at minimum grain density were found to constitute about 25% of the total. The relativisitic rise to plateau is being expressed in terms of percentage of primary grain density. The mean excitation potential for silver bromide also is being determined. The saturation in the primary and secondary grain densities has been studied and seems to be understood.

This work is scheduled to appear as a separate report[1] and will be submitted to Nuovo cimento. Work on the theory of particle tracks is continuing.

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[1] Jack W. Patrick and Walter H. Barkas, The Grain Density of Emulsion Tracks, UCRL-9692, June 1961.

NEUTRONS PRODUCED IN HEAVY-ION REACTIONS

William G. Simon and Harry H. Heckman

The measurement of the energy and angular distributions of neutrons emitted from heavy-ion-induced interactions is continuing. Emulsion exposures have been made in order to determine the thick-target yields of neutrons from collisions of O^{16} ions at 167, 142, 116, and 97 Mev on gold and aluminum targets. The emulsions were placed at 15-deg intervals from 0 to 165 deg with respect to the incoming O^{16} beam.

The proton recoils in the emulsion are being measured by using an automatic readout microscope, and the resulting data are being processed by the IBM 650.

CHARGED PARTICLES FROM HEAVY-ION REACTIONS

Donald V. Reames and Harry H. Heckman

The magnetic analysis of the charged particles produced at 0 deg by the bombardment of various thick targets with 167-Mev O^{16} ions is continuing. Gold, aluminum, nickel, and silver targets have been bombarded, and the cross sections for the production of protons, deuterons, tritons, α particles, He^3's, and Li^8's have been determined for the interactions in gold and aluminum. Typically, these cross sections have been measured in an energy range from 5 to 75 Mev for gold, and 5 to 110 Mev for aluminum.

It has been observed that the general character of the curves does not change with the target; for example, the ratio of the cross section for α particles to that for protons at high energies is of the order of 10^2 for both aluminum and gold. The magnitude of the cross section for a given particle at a given energy is about 10 times as high for aluminum as for gold, however. The cross section for, say, α particles from gold is 8 mb at the peak (approx 35 Mev) and falls to 4 μb at the maximum energy (77 Mev).

The mechanism for the production of these high-energy particles is not yet fully understood. It has been proposed, however, that an attempt be made to observe the actual interaction of the O^{16} in emulsion to see if, for example, the target nucleus and the projectile (or part of it) are still present after the interaction or if a compound nucleus has been formed.

An investigation of the angular distribution of charged particles has also been undertaken and it has been found that they are quite strongly peaked in the forward direction, though this evidence is as yet only qualitative and is not complete beyond 60 deg in the laboratory system.

SPACE PHYSICS

Harry H. Heckman

A successful recovery was made of an emulsion package that was exposed in the lower regions of the inner Van Allen radiation belt. The flight trajectory reached an altitude of 1185 kilometers. The emulsion was irradiated for about 400 seconds. By removing a section of the aft ring of an Atlas nose cone, it was possible to decrease the entrance "window" to the emulsions to approximately 0.2 g/cm^2. Proton energies as low as 12 Mev then can be observed. The proton energy spectrum between 12 and 37 Mev has been measured. The measurements above 37 Mev are now being made. The low-energy data show a broad maximum at approximately 30 Mev. It is possible that this maximum is related to the structure observed in the energy distribution near 80 Mev in a previous flight (J. Geophys. Research 66, 351 (1961)). No maxima at these energies are expected when the sole source of the inner belt is the cosmic-ray neutron albedo. A postdeadline paper on this work was presented at the April meeting to the American Geophysical Union, Washington, D.C. The experiment is being carried out in cooperation with L. Rosen and A.H. Armstrong, Los Alamos Scientific Laboratory.

THEORETICAL GROUP

David L. Judd

PHYSICS OF THE NUCLEUS

A paper dealing with the charge division in fission is nearing completion (with Marshall Blann, University of Rochester). The slight redistribution of charge in fission and the fluctuations in charge around the most probable value are treated in a unified way, incorporating and extending previous considerations of the problem by R.D. Present, Hill, and Wheeler and Fong. A closed formula for the most probable charge on a fission fragment of a given mass is derived under certain assumptions, and the statistical and quantum-mechanical fluctuations around the most probable value are shown to be given by a Gaussian distribution, with a width constant for which a closed formula valid at all temperatures is given.

The above treatment of fluctuations is found to be rather general and may serve as a basis for the discussion of a variety of other problems, one of which--the division of mass in the fission of nuclei lighter than radium--is considered in the paper with Blann. Other applications, namely the discussion of the fluctuations in the kinetic energy of fission fragments, in their angular momenta and in their excitations, are under way. (Wladyslaw Swiatecki)

The analysis of the data from the time-of-flight experiment on fission fragments and neutrons from Cf^{252} continues (with Stanley G. Thompson and Harry R. Bowman of Chemistry). The results on the angular and energy distributions of the neutrons are being prepared for publication. (Wladyslaw Swiatecki)

Work by Swiatecki during part of the past 6 months (on leave of absence at the University of Aarhus, Denmark) included completion of a paper with S. Cohen (Argonne National Laboratory) entitled "The Deformation Energy of a Charged Drop. IV. Evidence for a Discontinuity in the Conventional Family of Saddle-Point Shapes." A preprint of this paper is available as a report from the Physics Institute, University of Aarhus. The work deals with the foundation of the liquid-drop theory of fission and aims at a broad survey of the principal features of the deformation energy of a nucleus, idealized as a uniformly charged drop. The existence of at least two critical regions in the periodic table of elements is recognized, the first in the general neighborhood of medium-weight nuclei around silver, where fission first becomes theoretically distinguishable from spallation, and the second in the general neighborhood of heavy elements around thorium, where changes in the qualitative features of fission are to be expected. These changes are associated with the appearance at this stage of stable or almost stable extremely elongated cylinderlike configurations of equilibrium of a charged drop. The existence of these configurations is associated with the predicted disintegration of heavier nuclei into three or more comparable fragments.

The problem of the existence and stabilities of various configurations of equilibrium of nuclei (represented as idealized drops) is formulated in

the paper in question, and semiquantitative estimates of some of the most important features of these configurations are made.

The fully quantitative treatment of the above problem with the aid of an IBM 704 computer is the subject of continued study with S. Cohen. (Wladyslaw Swiatecki)

An attempt was made to understand the reason for the anomalous behavior of fission thresholds and spontaneous fission half-lives. A connection between this problem and the anomalous location of the valley of β stability in heavy elements has been found, but no satisfactory quantitative explanation of the anomalies has so far been obtained. (Wladyslaw Swiatecki)

An experimental investigation of the fission of a charged drop of liquid is under way (with D. Martin, Stanley G. Thompson, and Harry R. Bowman, Chemistry). Preliminary studies of the disintegration of a drop of water suspended in transformer oil and distorted by an external electric field have been filmed in slow motion and show different types of division into two or more fragments. A quantitative study of the disintegration of a drop of oil falling freely in a vacuum and charged by passage through an electron beam is planned. (Wladyslaw Swiatecki)

At the suggestion of Professor Kenneth M. Watson, the collective excitation of nuclei is being considered when the ground state of nuclear matter is taken to be the superconducting state. Using the Bogoliubov canonical transformation, secular equations have been derived in the Sawada approximation for the collective excitation. Preliminary solutions of these equations indicate that stable collective eigenmodes of excitation may exist for energies of excitation small in comparison to the energy gap. (Philip G. Burke)

In collaboration with William Laskar (Alvarez group), a general formalism describing the scattering of nucleons and deuterons by light nuclei in the Wheeler resonating group approximation has been set up.[1] The interaction assumed is central with arbitrary spin and space exchange dependence. Particular solutions of these equations for deuteron-deuteron scattering have given results reasonably in agreement with experiment.[2] (Philip G. Burke)

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[1] Philip G. Burke and William Laskar, Nucleon and Deuteron Reactions with Light Nuclei, Rev. mex. fis. (to be published, Summer 1961).

[2] Philip G. Burke and William Laskar, Four-Nucleon Reactions with Central Forces, Proc. Phys. Soc. 77, 49 (1961).

THEORY OF WEAK INTERACTIONS

A thesis has been written on two problems of structure in theory of weak interactions.[3] Part I of this thesis, Radiative Pion Decay into Electrons, has already been published in the Physical Review. Part II, Electromagnetic Properties of a Charged Vector Meson Intermediary in Weak Interactions, is being prepared for publication. (James A. Young and Sidney A. Bludman)

A new weak-coupling scheme is being developed. In this scheme, the lepton and strongly interacting particle currents in the universal Fermi interaction are both split into two parts, even and odd. The requirement that the over-all interaction be even then allows $2\mu \rightarrow 2e$ processes while forbidding single $\mu \rightarrow e$ conversion, and requires that the nonleptonic decays come about through the coupling of the strangeness-changing current J_μ' with itself. This compels us to a theory which differs from the schizon scheme by allowing $\Delta S = 2$ leptonic processes, and from the veton scheme by associating electrons with muon-neutrinos in strangeness-changing processes. (Sidney A. Bludman)

Production cross sections for vector bosons as postulated for the weak interactions are being studied. In particular, the cross section for the production of a pair of bosons from an electron-positron pair was calculated and compared with the background of muon or pion production. The cross section for boson production by high-energy neutrinos in a Coulomb field is now being investigated. In all cases the most general electromagnetic properties of a spin-1 boson[3] are assumed, namely a charge, magnetic moment, and electric quadrupole moment. (Helen Hartmann)

THEORY OF π AND μ MESONS

It is believed that μ mesons and π mesons if they are captured by atoms are captured through an Auger mechanism into a state of rather high energy. An investigation is under way of the various mechanisms by which the mesons, when captured in light elements, can make transitions to states of lower energy before they are absorbed or decay. The transition probabilities per unit time for the various mechanisms of decay and for the competing processes of refilling the 1s state have been developed, and accurate values for the associated energy levels and approximations for the associated wave functions are being obtained. The modification of the Coulomb potential due to the presence of the atomic electrons has been derived, and is being used to obtain what are hoped to be rather accurate values for the shift of the energy levels due to the presence of the atomic electrons. The IBM 704 is being used to obtain the energy-level shifts by integrating the Schrödinger equation. (Coates R. Johnson)

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[3] James A. Young, Two Problems of Structure in the Theory of Weak Interactions (Thesis), UCRL-9563, Feb. 8, 1961.

FIELD THEORY

The two most important general physical consequences of relativistic field theory are the CPT theorem and the connection between spin and statistics. However, the postulates of relativistic field theory themselves are subject to considerable doubt. They have not been shown to admit of any nontrivial rigorous solutions, and they are based upon the concept of the points of a space-time continuum. As such points are both in practice and in principle inaccessible to experimental definition, the concept may be inadequate for a description of nature, as well as being the origin of the well-known mathematical difficulties with the theory. Also, the postulates are very restrictive even within the general realm of local field theories, thereby excluding such important theories as Heisenberg's and the recent theory of Nambu.

An alternative approach to elementary particle physics is based on the S matrix. It has been shown, by using this approach, that the CPT theorem is a consequence of much more basic requirements--the superposition principle, the conservation laws, and relativistic invariance. No reference to space-time points is needed, and the use of commutation relations or their equivalent is avoided. The proof is based on the use of complex Lorentz transformations introduced in this connection by Hall and Wightman and by Jost. Wightman's theory of the vacuum expectation values of field operators is not required. (Henry P. Stapp)

The connection between spin and statistics is also being examined from this viewpoint. This connection can be shown to follow in any theory in which the functions describing a process and the CPT inverse process (these functions are analytic continuations of each other as a consequence of the above-mentioned requirements) give a unit S matrix in the no-scattering limit for normal-ordered variables. Work is in progress to show that this latter is a consequence of unitarity and a postulated analyticity requirement on the S-matrix elements. This requirement, together with those mentioned above, has been cast into the form of a postulative S-matrix theory which is apparently nonequivalent to postulative field theory, and which does not have the objectionable features of the latter set forth above. The analyticity requirement is contained in a postulate of maximal analyticity which states that the functions describing the S matrix are analytic throughout the interiors of their physical sheets, where the boundaries of the latter are specified by the unitarity requirement in terms of the mass spectrum. (Henry P. Stapp)

An attempt is being made to make a Lamb-shift-type quantum electrodynamical correction to energy levels in a strong Coulomb field. Currently a number of corrections to energy levels in heavier elements have been made. These include the correction for screening effects by Cohen,[4] the correction for finite nuclear size by Schawlow and Towns,[5] and the vacuum polarization correction of Wichmann and Kroll.[6] There have been independent measurements of the nuclear size by Hofstadter,[7] and there have also been

[4] Revs. Modern Phys. 27, 363 (1955).
[5] Phys. Rev. 100, 1273 (1955).
[6] Ibid. 101, 843 (1956).
[7] Ann. Rev. Nuclear Sci. 7, 231 (1957).

precise measurements of energy-level differences by Schacklett and DuMond.[8] This suggests that if one could obtain a valid Lamb-shift type of correction one would have the possibility of making an experimental consistency check of the theoretical corrections. In order to make the Lamb-shift type of correction one needs the relativistic Green's function for the Dirac equation with a Coulomb field. Wichmann and Woo[9] recently gave the nonrelativistic Green's function in the presence of the Coulomb field in closed form. It might be hoped that the sum over energy states which gives the relativistic Green's function in our case could also be given in closed form. In the event that this cannot be done it is hoped that a sufficiently accurate approximation to the Green's function may be obtained by including only the first few angular momentum eigenstates in the sum. It is hoped that, having obtained some closed expression for the relativistic Green's function, one can accomplish the usual renormalization to give the energy of the electron in the presence of the external field. (Michael M. Austin)

The implications of local causality are being investigated. It would seem that local causality, along with other established principles such as Lorentz invariance and translation invariance, imposes an upper limit on the magnitudes of measurable physical observables. In particular, an attempt is being made to prove that the elastic-scattering amplitude of two scalar particles approaches a constant at infinite energy. In general it seems possible to find an upper limit of $f(x)$ throughout x when f is measured in some restricted interval of x, where f is some physical quantity and x is one of the variables on which it depends. (Michel Nicola)

The approach to causality and dispersion theory outlined in an earlier paper[10] was developed further.

Spectral representations for the Green's functions were obtained by a plausibility argument without recourse to perturbation theory through the imposition of certain plausible boundary conditions. They permit the continuations of the Green's function into a complex space, not only in the energy and scattering angles but also in the masses of the particles entering and leaving the reaction.

These reduce to representations of the Mandelstam type for the scattering amplitude of the latter so extracted from the Green's function. In its general form this development presents a more complete analytic picture. (Maurice Neuman)

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[8] Phys. Rev. 106, 501 (1957).

[9] Preprint (University of California).

[10] Maurice Neuman, Causality of the Lorentz Group, UCRL-9260, June 8, 1960.

PHENOMENOLOGY OF STRONG INTERACTIONS

In the standard Adair analysis of resonances and quasi-stable particles the spin is determined by the decay angular distribution for those quasi particles that are produced in the forward or nearly forward direction. For S-wave production the characteristic angular distributions extend to all production angles. However, both S- and P-wave production is not uncommon. This case has been examined and characteristic angular correlations between the decay and production angles for spin-3/2 particles have been obtained. Although the general form is a complicated six-parameter correlation function, a number of averages that may be expressed in terms of (related) single-parameter forms have been found. Several averages of decay angular distributions that are true for all production angles with no limitation on the number of partial waves have also been obtained. A report of this work has been issued.[11] (Henry P. Stapp)

An extensive program of analysis of the world's proton-proton scattering data up to 400 Mev has been continued (with Michael J. Moravcsik and H. Pierre Noyes, LRL, Livermore). About a dozen rather similar solutions of the potential type (i.e., resembling those obtained from current potential models) have been obtained. The fits are better by orders of magnitude than the previous potential-model fits, but still are not satisfactory by statistical standards. Certain data contributing large contributions to χ^2 have been singled out as deserving of experimental re-evaluation. Forms for the energy dependence are relatively simple analytic functions suitable for substitution in expressions where the nucleon-nucleon scattering amplitude occurs. A limited search for solutions of nonpotential type has not uncovered any such solutions. Work is in progress to replace our simple forms for the energy dependence by forms having more direct connection to dispersion theoretic quantities. These more complicated forms are not as suited to large-scale searching and are less convenient for substitution in formulas for other processes, but they should be useful at a more fundamental level. (Henry P. Stapp)

An extensive calculation of the interactions of elementary particles according to the relativistic statistical model is being set up. The goal is to develop a method that will be useful for very high energies, e.g. in the region 100 to 300 Bev. The evaluation of phase-space integrals has been reduced to a single contour integration which can be approximated by using the steepest-descents technique in a way closely analogous to that used in obtaining the Stirling approximation for factorials. For more than two particles, the approximation should be better than 3% for all energies. Sums of the phase integrals over all possible states will be carried out exactly, with strangeness, charge, baryon, and isotopic-spin conservation retained. The program for this calculation has been written for the IBM 709 and is now being debugged. (Joseph V. Lepore and Robert J. Riddell, Jr.)

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[11] Henry P. Stapp, On the Identification of Spin-3/2 Resonances, UCRL-9526, Dec. 1960.

Work is proceeding (in collaboration with J. M. Cornwall) on a derivation of the Einstein gravitational field equations from the assumption of energy-momentum feedback in a flat-space formalism. This work is in part an extension of an earlier paper,[12] and in part was reported by Cornwall at the December meeting of the American Physical Society in Berkeley. (Sidney A. Bludman)

A method for finding the invariant scattering amplitudes which satisfy dispersion relations was used to find the invariant functions for the deuteron electro-magnetic form factor. The invariant functions thus found were shown to be free from kinematical singularities. (Michel Nicola)

S-MATRIX THEORY OF STRONG INTERACTIONS

The major local development of the past six months in the study of strong interactions through the analytic continuation of the S matrix has been a unification of the approach to high- and low-energy phenomena. The approximation procedure (sometimes called the "strip approximation") is still restricted to the longer-range forces (or equivalently to the smaller momentum transfers) but it is now recognized that all energies should be considered. Papers concerned with the general basis for this new point of view have been written by Chew and Frautschi.[13] Applications of the new method in various situations are described in the following four paragraphs.

A paper has been completed in which a "generalized potential" has been defined which can be applied, within the S-matrix framework, to relativistic scattering at arbitrary energies. This potential is necessarily energy-dependent and complex (above the inelastic threshold), but it determines the elastic scattering in essentially the same way as an ordinary nonrelativistic potential. With the help of this potential we gave an unambiguous criterion for distinguishing in principle between a "dynamical resonance" and an "unstable elementary particle." (Steven Frautschi and Geoffrey Chew)

The strip approximation to the Mandelstam representation has been applied to the pion-nucleon problem, and the basic equations given. The asymptotic behavior of the invariant amplitudes in the physical regions has been discussed in terms of the unitarity condition on partial-wave amplitudes, the constancy of high-energy scattering cross sections, and the Pomeranchuk theorem, and it is shown to imply that no subtractions should be necessary except for the $J = 1/2$ wave of the pion-nucleon channel and the $J = 0$ wave of the $\pi + \pi \rightarrow N + \overline{N}$ channel, thus obviating the difficulties encountered earlier when higher waves were treated by subtraction.

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[12] Sidney A. Bludman, Equivalence Principle, General Relativity, and Their Observational Tests; UCRL-9176, March 1960.

[13] Phys. Rev. Letters 5, 580 (1960). See also Geoffrey F. Chew and Steven S. Frautschi, A Dynamical Theory For Strong Interactions at Low Momentum Transfers but Arbitrary Energies, UCRL-9510, Nov. 4, 1960 (to be published in Phys Rev.). See also Geoffrey F. Chew, A Unifed Dynamical Approach to High- and Low-Energy Strong Interactions, UCRL-9515, Jan. 3, 1961 (to be published in Revs. Modern Phys.).

Approximate solutions of these equations are now being studied. (B. M. Udgaonkar and Virendra Singh)

The double-strip approximation to the spectral functions determining scattering amplitudes for strongly interacting particles is being applied to the nucleon-nucleon problem. This problem is complicated by the necessity of treating together ten independent amplitudes, which obey coupled equations. The essence of the problem is to write down the equations satisfied by the absorptive parts of these amplitudes, which follow from a consideration of the elastic unitarity condition in each of the three reaction channels. In the direct channel this leads to integral equations expressing the double spectral functions in the strip regions which run parallel to the zero-energy axis in terms of the absorptive parts of the nucleon-nucleon amplitudes. In the crossed channels the equations relate the double spectral functions in the remaining strips to the absorptive parts of the reaction amplitude for nucleon-antinucleon annihilation into two pions, the latter being an analytic continuation of the pion-nucleon scattering amplitude. It has been found convenient to express the unitarity conditions through the Jacob and Wick[14] helicity amplitudes, thus avoiding extensive calculations of traces. Attention is also being paid to the problems of single spectral functions and subtractions. (John M. Charap, Elihu Lubkin, Antonio Scotti, Ivan J. Muzinich, and Edward Jones)

The scattering amplitude arising from a potential, direct and exchange, which can be expressed as a superposition of Yukawa potentials, satisfies a Mandelstam representation. A consideration of unitarity for this problem results in a set of coupled integral equations for the double spectral function which is closely analogous to that which arises in field theory in, for example, the double strip approximation of pion-pion scattering.[15] Furthermore, considerations by Regge[16] have indicated that the double spectral function will undergo oscillation for large values of one of its arguments. The nature and development of these oscillations and of the build-up of the asymptotic behavior of the double spectral function are of considerable interest, and accordingly a program is being written (Edwin Towster, programmer) for the IBM 709 which will permit calculations of the double spectral function to be performed for a very wide class of potentials. Considerable attention has been paid to the numerical difficulties anticipated because of the oscillations and to those concomitant with the principal-value integrations to be performed. (John M. Charap)

Calculations on the low-energy 2π, 2γ vertex interaction have been carried out based on the Mandelstam representation. Because of Lorentz and gauge invariance only two independent amplitudes are involved. On the basis of unitarity limitations on the asymptotic behavior of these amplitudes, only $j = 1$ subtraction in the $\gamma + \pi \rightarrow \gamma + \pi$ channel and a $j = 0$ subtraction in the $\gamma + \gamma \rightarrow \pi + \pi$ channel are allowed. No over-all subtraction constants are required and the Thomson limit is automatically maintained. Only the effect of 2π intermediate states has been considered. The odd-j $\pi\pi$ contribution

[14] M. Jacob and G. C. Wick: Ann. Phys. 7, 404 (1959).

[15] Geoffrey F. Chew and Steven S. Frautschi, A Dynamical Theory For Strong Interactions at Low Momentum Transfers but Arbitrary Energies, UCRL-9510, Nov. 4, 1960.

[16] T. Regge, Nuovo cimento 14, 951 (1959).

involves the amplitude for the process $\gamma + \pi \rightarrow 2\pi$ which was analyzed by Wong and shown to be proportional to a pseudo-elementary constant Λ. Even with a $\pi\pi$ P-wave resonance the resulting correction is negligible ($\lesssim 1\%$) if we use the value of Λ estimated by Wong on the basis of π^0 decay and confirmed by Ball in connection with photopion production on nucleons. A moderately important contribution comes from the $\pi\pi$ S-wave interaction. If the pion-pion coupling constant λ is chosen to be of the order of -0.20 (see below), this effect is approx 10% in $\gamma + \pi \rightarrow \gamma + \pi$ scattering. For $\gamma + \gamma \rightarrow \pi + \pi$, the correction for the I = 0 state at threshold is positive and approx 100% of the Born approximation. As the energy is increased, the correction quickly changes sign.

The $\pi\pi$ S-wave phase shifts needed in the above calculations are obtained by using crossing symmetry relations given by Chew and Mandelstam. For a $\pi\pi$ P-resonance position $\approx 20\ \mu^2$ (μ being the pion mass), we find that λ in the interval -0.20 to -0.15 is in good agreement with the $\pi\pi$ S-wave enhancement observed by Abashian et al. in $p + d$ collisions. The S-wave interaction is found to be much stronger in the I = 0 state than in the I = 2 state. (Bipin Desai)

One-dimensional dispersion relations for the partial-wave helicity amplitudes for the process γ (virtual) + γ (real) $\rightarrow \pi + \pi$ have been derived from the Mandelstam representation. Solutions for the ensuing integral equations were obtained within the approximation of retaining the contribution of only the pole term to the unphysical cut. The resulting S-wave solution was used in the calculation of the cross section for electromagnetic pion pair production. The results of calculation show that the effects of the π-π final-state interaction may be measured in the presence of nuclear pion pair production provided that the momentum transfers to the nucleus are sufficiently small, say 1/2 in unit of a pion mass in the case of an incident photon of 6 Bev. (Yongduk Kim)

Work is continuing upon the theory of π^0 photoproduction from complex nuclei within the framework of the optical model. An analysis of a possible experiment may lead to information about the nucleon pair correlation function. (Robert Traxler)

An attempt has been made to characterize the interaction "range" by requiring the two-particle scattering amplitude, in the barycentric system, to be an analytic function of three or two (dependent on the choice of coordinate system) complex variables over a certain restricted region. The following model has been studied: A sufficiently localized wave packet ψ_i is scattered by a potential $V(r)$ (where $V(r)$ is bounded by $\exp(-\lambda r)$ as r becomes large). Let the scattered part of the outgoing packet be called $\psi_s(\bar{p})$, where $\bar{p}$ is the physical 3-momentum. By solving the Schrödinger equation it can be shown that $\psi_s(\bar{p})$ can be analytically continued into $\psi_s(\vec{k} = \bar{p} + i\bar{q})$, where $|\bar{q}| < \lambda$. The corresponding region in complex $k \equiv \sqrt{\bar{k} \cdot \bar{k}}$ and $\cos\theta \equiv z \equiv (p_1 + iq_1)/k$ has been worked out, with the results:

(I) ψ_s ($k = u + iv$, $\cos\theta = z$), for k fixed, is analytic in an ellipse with foci at (-1, +1) and with semimajor axis $M = \sqrt{1 + \frac{\lambda^2 - v^2}{|k|^2}}$;

(II) for k real, the Schrödinger equation with a Yukawa potential yields a partial-wave expansion with $M = 1 + \frac{\lambda^2}{2p^2}$;

(III) the Lehmann ellipse for the relativistic amplitude $T(p, \cos\theta)$ yields

$$M = \sqrt{1 + \frac{1}{p^2} \frac{1}{p^2 + m^2} C} \text{ ; and}$$

(IV) the Lehmann ellipse for relativistic Im $T(p, \cos\theta)$ yields

$$M = 1 + \frac{1}{p^2} \frac{1}{p^2 + m^2} 2c.$$

(I) and (II) are nonrelativistic. The final goal is the relativistic generalization of (I) to the two-particle scattering amplitude. (Jack Wong)

PLASMA PHYSICS

In the Alfvén wave experiment (Hothouse I), current is sent between an outer cylindrical shell and an electrode projecting slightly through an insulating end plate of the cylinder.[17] Two effects of finite plasma resistivity have been calculated. One is the phase difference to be expected between the applied current and voltage. It is found that if the plasma conductivity is not infinite, the cylinder of plasma appears inductive to the source. However, the phase difference was calculated to be too small to be observed in this experiment. This agrees with the experimental result of no phase difference.

The other effect is on the propagation velocity of a pulse. The damping of the various frequency components in the pulse is a function of frequency and is proportional to the plasma resistivity η. To first order in η, all frequencies propagate at the Alfvén velocity. However, the unequal damping of the various frequencies distorts the pulse shape as time progresses. The result is that the peak of the pulse does not travel at Alfvén velocity. It was found that this effect is quantitatively too small to explain the experimental observation that the pulse velocity exceeds the expected Alfvén velocity by about 10%. (Theodore G. Northrop)

A comprehensive paper has been completed on the subject of adiabatic charged-particle motion. The equations of motion of a charge particle in an electromagnetic field have been used to obtain the so-called "guiding

[17] Alan W. DeSilva, William Cooper, and John Wilcox, Alfvén Wave Reflections and Propagation Modes, UCRL-9496, Feb. 1961.

center" motion. In a slowly varying field the particle motion is approximately a rapid rotation about a circle whose center (the guiding center) has velocity components along and at right angles to the magnetic field. The equations governing the guiding-center motion have been deductively obtained for the general time-dependent field. Several unfamiliar terms appear because the electric field component perpendicular to the magnetic field and the time dependence of the magnetic field were assumed to be of zero order in the radius of gyration, rather than first order. These less familiar terms have been illustrated via practical cases where they occur.

The modifications of the guiding-center equations required for relativistic particles have been discussed. Comparison of the relativistic and nonrelativistic expressions shows a modification of existing nonrelativistic terms by effects of order v^2/c^2. In addition, two entirely new guiding-center drift terms appear. These are in the direction of the component of the electric field that is perpendicular to the magnetic field. They are purely relativistic effects. A geometric explanation of one of the terms has been given.

The three adiabatic invariants of the particle motion have been defined and the invariance proven for the general case of time-dependent fields. Several applications have been made of the guiding-center equations of motion and of the adiabatic invariants. Finally, deviations from the adiabatic predictions have been discussed. (Theodore G. Northrop)

The behavior of a plasma in the mirror geometry is being investigated by means of an energy principle derived by William Newcomb. The change of energy under an infinitesimal displacement of the plasma is expressed in integral form. This integral is then minimized by variational techniques. The sign of this minimized integral determines the stability of the system. A stability criterion has been derived for the case of low β ($p/B^2 << 1$) and periodic magnetic fields. The stability for the case of magnetic lines of force tied at end plates is being investigated. A paper discussing oscillation modes in the triax pinch device has been published. (Shalom Fisher)

The Green's function has been obtained for the radiation of hydromagnetic waves in a fully ionized pressureless plasma permeated by a strong constant magnetic field. The source of the waves is considered to be a current injected into the plasma, as was done in the work by Karplus,[18] where an infinite perfectly conducting plasma was considered. This work has been extended to treat a plasma with small but finite resistivity in an infinite cylinder. The magnetic field is taken parallel to the axis of the cylinder. It is assumed that the frequency components of the waves are small compared with the ion- and electron-cyclotron frequencies, that the current source has no azimuthal component, and the wave lengths of the waves are large compared with the radius of the cylinder. It is found that within the above approximations the waves are damped by the finite resistivity but there is no dispersion in wave velocity. (David L. Sachs)

[18] R. Karplus, Phys. Fluids 3, 800 (1960).

Various perturbation techniques in quantum statistics have been studied and evaluated with the aim of calculating the contribution of the first Abe nodal expansion term to the thermodynamic functions of a plasma. Some preliminary integral calculations have been made. (Sidney Putnam)

Recent literature on the interaction of the solar wind with the geomagnetic field has been reviewed with particular emphasis on the work by Beard.[19] Beard's assumption that the existence of a current sheath shielding the plasma from the geomagnetic field is compatible with Maxwell's equations has been verified and his theory of the boundary layer corrected. In particular, the condition of pressure balance is found to be contained in the equations describing the structure of the layer, and does not have to be imposed as additional information. In addition, the value of the magnetic field well inside the plasma is found to differ by a constant factor from that given by Beard. (Alan Macmahon)

ATOMIC PHYSICS

A numerical method has been developed to allow for the virtual excitation of energetically inaccessible states in the scattering of electrons and positrons by atoms. The method has been applied to the elastic scattering of electrons and positrons by atomic hydrogen. The work on electron-hydrogen atom scattering is now being extended with Harry M. Schey (LRL, Livermore), and a code for the IBM 709 has been written in which arbitrary hydrogen atom states can be included in the expansion of the total wave function. Finally, in collaboration with Schey, explicit forms for the polarization and correlation tensors arising in electron-hydrogen atom scattering have been derived. (Philip G. Burke and Valerie M. Burke)

By use of estimates of the most probable potential existing between hydrogen atoms,[20] the phase shifts for hydrogen-hydrogen collisions are being calculated for thermal energies. Numerical integration employing the WKB approximation for phase shifts is under way. Tentative results show that angular momenta as high as $\ell = 10$ contribute, and suggest a near resonance at $\ell = 0$. Subsequent calculation will determine all phase shifts and resultant cross sections. (John Gillespie)

Goldstone perturbation theory has been applied to atomic systems, with particular application to the neutral boron atom. The Hartree-Fock potential was approximated by a screened Coulomb potential. Second-order terms have been found sufficient to give the correlation energy among the two 1s electrons. For the two 2s electrons, the second-order term was found to be too high by a factor of approximately three if good agreement with experiment is to be obtained. Calculation of the third-order term improves the calculation, since the third-order term is found to be approximately 44% of the second-order term and is of opposite sign. Error in the potential may account for the remaining discrepancy, and this problem is now being investigated. (Hugh Kelly and Valerie M. Burke)

[19] David B. Beard, J. Geophys. Research 65, 3559 (1960).

[20] J. O. Herschfelder and J. W. Linnett, J. Chem. Phys. 18, 130 (1950).

The wave function of an electron scattered elastically from a hydrogen atom in its ground state is being studied. A variational approach is used to find the phase shift and the wave function for each partial wave. The partial wave $\ell = 1$ is now being completed, and higher ℓ will follow. (Robert Armstead)

The general problem of the effect of correlations on atomic properties is being studied. The random-phase approximation, as used by Gell-Mann, Brueckner, and Sawada in the study of the infinite electron gas,[21] has been formulated for the finite case in which the excitations carry angular momentum. The solution to the equations obtained will make it possible to calculate atomic properties within the random-phase approximation, i.e., with some correlations present. Wave functions are now being sought which will be used as a basis for the solution. (Philip Altick)

ACCELERATORS

Bevatron External Beam Program

Work has continued (with Philip Meads and H.C. Owens) to select the parameters for a two-magnet, Piccioni-type extraction system for the Bevatron. Many calculations of predicted extracted beam shapes have been made with orbit codes for different choices of position of the energy-loss target and strength and focusing in the deflecting magnets. In addition, a linearized code was written to permit a more systematic, though less accurate, search in the space of these parameters. This project was aided by Dr. Andrew Sessler during a visit he made here last December. As a result a relatively limited set of possible parameter choices emerged. These calculations are being extended to lower energies, and to a larger radial position of the second magnet, so as to permit a final determination of the system. (Alper A. Garren)

88-Inch Cyclotron

Many calculations are still being made (with Ardith Kenney, H.C. Owens, and Jonathan Young) concerning this machine. Among the most important are the following.

The initial group of measurements of the full-scale magnet has been made, and subjected to the same type of computer analysis as was applied to the 1/5-scale model magnet data. Again we find that by running suitable currents in the circular trimming coils (calculated by Linear Programming methods--see previous semiannual reports) it is possible to achieve a field in which the particles retain sufficient isochronism and stability against vertical and radial oscillations during acceleration. However, our tentative decision to attempt extraction from a larger radius than formerly, after the particles have had to traverse the $\nu_r = 1$ radial resonance, has led to more careful studies of the effect of first harmonic error in the field in this region, leading in turn to more stringent error tolerances. It appears that with iron corrections already made, and with the valley correcting coils, these tolerances can be met.

[21] M. Gell-Mann and K.A. Brueckner, Phys. Rev. 106, 364 (1957), and K. Sawada, Phys. Rev. 106, 372 (1957).

Our concern about resonances in the extraction region have been stimulated by the vertical blow-up of the beam in the UCRL spiral-ridged cyclotron at 20.5 inches. After pursuing a number of hypotheses which were disproved, we obtained some point measurements which we analyzed with our orbit codes. These indeed showed a linear vertical instability setting in at 20.5 inches, which could be attributed to a sharp bump in the flutter caused by the presence of shims at the ends at the spiral hills. The damage is caused by a term, $-\frac{R^2}{2N^2}\frac{d^2F^2}{dR^2}$, in the equation for ν_z^2. Here N is the number of sectors, $F^2 = \langle \Delta B \rangle^2 / \langle B \rangle^2$ is the flutter.

Calculations on extraction have lately centered on trying to find a shape for the electrostatic channel that would fit particle orbits at both high and low magnet excitations. This is difficult, because saturation alters the magnet field shape, but we have succeeded with the model magnet fields for two cases chosen to strain the channel's flexibility to the maximum extent. (Alper A. Garren)

Synchrotron Injection Study

The problem of maximizing injection efficiency for weak-focusing synchrotrons has been studied by methods similar to those developed by workers at Saclay in France. The French study (whose numerical results applied only to their Saturne accelerator) has been generalized and extended, and an IBM-709 code has been developed (with Herman Grunder, Mechanical Engineering) to yield numerical results for a wide variety of possible synchrotron parameters. This study is expected to be important in optimizing injector and inflector parameters of the new injection system for the Bevatron. It will also be applicable to the determination of parameters of a biomedical heavy-ion synchrotron which has been under informal consideration for several months at this Laboratory. The code may be applied, with minor modifications, to strong-focusing synchrotrons. Particle losses to inner and outer vacuum chamber walls and to the inflector surfaces are calculated, including losses resulting from radial phase oscillation motions after rf turn-on. The inclusion of losses due to space-charge forces is still under study. Preliminary results have correlated well with observations of present injection efficiency at the Bevatron. (David L. Judd)

Particle-Orbit Study for Biomedical Heavy-Ion Synchrotron

An informal study of a possible future biomedical synchrotron has been under way for several months. Certain orbit properties of weak-focusing synchrotrons have been estimated, with particular attention to the provision of straight sections somewhat longer than usual. Emphasis has recently turned to a study of alternating-gradient synchrotrons for this purpose, and here also possibilities for long straight sections are under study, along lines suggested and developed to some extent by Dr. Hartland Snyder of the Brookhaven National Laboratory. Dr. Lloyd Smith has assisted in the preliminary consideration of this problem. (David L. Judd)

Nonlinear Spiral-Ridge Cyclotron Orbit Instabilities

In connection with the analysis of the behavior of the UCLA spiral-ridge cyclotron (see report above, of Alper Garren's work) consideration was given to the possibility that the observed axial orbit instability might be due to abnormally large higher radial derivatives of the azimuthally averaged magnetic field in a small radial region near the outside of the magnet. This possibility was of interest because most digital orbit calculations and many analytical approximations consider only linear effects in the axial or vertical direction. An approximate analysis of nonlinear vertical effects was pushed far enough to show that under some conditions a nonlinear nonresonant loss of axial stability could result from a very sharp knee in the average radial field profile, corresponding to locally large higher derivatives. This study has not been continued because of the press of other work, because alternative explanations of the observed behavior seemed equally plausible, and because no very sharp knee in the field profile is expected on the 88-inch cyclotron being constructed at this Laboratory. (David L. Judd)

Synchrotron Beam Resonance with a Parasitic Accelerating-Cavity Mode

Some thought has been given to the interaction of an intense particle beam in a synchrotron with a high-frequency resonant electromagnetic mode of the accelerating structure (with V. Kelvin Neil, LRL, Livermore). Such an effect has been observed on the Bevatron, and could perhaps become very troublesome at the higher beam intensities expected as a result of the Bevatron improvement program now under way. Enough work has been done to indicate that a reliable analysis must include a rather detailed study of the self-consistent charge and field distributions at the ends of an intense particle bunch. This study is still in progress. (David L. Judd)

HIGH-ENERGY PHYSICS

By use of the Alvarez group 72-inch hydrogen bubble chamber, and in collaboration with workers in the Alvarez group, information has been obtained on the pion-pion cross section in the $T = 1$ and $T = 2$ states for the total pion energy in the range $\omega^2 = 5\mu^2 - 25\,\mu^2$. (Philip G. Burke)

Progress has been made towards an automatic event-type processing routine which uses the current KICK-type subroutines (with Silverio P. Almeida, Alvarez group). An intermediate stage of this routine has been finished and tested. The routine has reached a stage in which physicists with rather complicated event-type programs to write may find it advantageous. (Philip G. Burke)

MATHEMATICS AND COMPUTING SERVICES GROUP

Kent Curtis

During the period of this report members of the Mathematics and Computing Service group have written the following programs for the Laboratory research groups.

I. Physics

A. Hydrogen Bubble Chamber Data Analysis

During the period November 1960 through April 1961 the following programming was done for the Alvarez Bubble Chamber Group:

PANG

The input and output sections of the spatial reconstruction code (PANG) were rewritten to take advantage of the input-output facilities of the IBM 709. Buffers were introduced and the on-line error listing was replaced by an off-line printer tape.

In order to save time at the scanning tables and the measuring projectors it was decided to measure 72-inch bubble chamber tracks in three views. (At present the scanner is asked to select the best stereo pair for each track in an event.) Appropriate modifications to the PANG code are now being checked. These modifications include the matching of unlabeled tracks in three views, selection of best stereo pair, and mass assignments from event type and spatial curvature.

A subroutine TEAST was written for incorporation into PANG. This is a general-purpose testing routine. The routine will test for "equality," "less than," or "in an interval." Masking and shifting operations may be specified prior to testing.

KICK

A subroutine BMAVG was written for KICK. This code selects the appropriate beam momentum from a table and averages it with the beam momentum calculated by PANG from measurements.

A series of KICK event-type subroutines was written for Experiment 2.

A subroutine "QVRT" was written for KICK. This routine is capable of performing several of the chores associated with the writing of KICK event types. "QVRT" was primarily designed to do multivertex processing, using the single-vertex fitting routine GUTS. The field-test version of QVRT has been used for several event types necessary for the associated-production experiment currently being analyzed.

EXAMIN

EXAMIN is the third large code in the Alvarez data-analysis system. The input data to this routine are the fitted quantities and associated errors as calculated by KICK. The EXAMIN system is composed of a standard input subroutine and various computation routines such as center-of-mass transforms, etc. There are also provisions for separating good, bad, and ambiguous event-type reports as written by KICK and compiling histograms of χ^2 values, production vs decay angles, etc. The system is currently in use for the following experiments: 04, associated production; 03, cascade; 08, K^- in deuterium; 07, K^- in hydrogen.

FILTER

The FILTER code written to find tracks digitized by a series of circular scanning slits (MP III A) has been rewritten for the modified measuring projector MP III B. This projector uses a vertex-oriented spiral scan instead of concentric circles.

LIBRARY

A series of programs (READN, QUEST, READD, SEPAR, SETUP, TRACK, LARK, BARK) was written for the K^- experiment (15-inch chamber). This collection of programs was written to keep a history of the events as they were routed though the various programs of the data-analysis system. The historical data on each event are kept on a "master list" tape. Some of the quantities on the master list for each event are: roll, frame, beam track number, date scanned, date measured, and event type, as well as quantities related to the outcome of analysis (PANG and KICK). These routines satisfy two needs: (a) keeping track of the events in the experiment for remeasurement requests or reprocessing by analysis routines, (b) providing means for obtaining fast summaries of the experiment.

LINGO

A design study of the computer system LINGO was completed. LINGO is designed to handle the data library of experiments in the Alvarez group and serve as an over-all supervisory control system for these experiments.

LINGO maintains a master index file of each event of the experiment on magnetic tape. This master index file will contain all scanning information on the event as well as a current history of the event as it passes through the measurement, analysis, and interpretation stages. Using the master index file tape, LINGO will also maintain a set of physics summary data tapes containing the analysis results of each event in the experiment. Using LINGO, the physicist will always have complete control of his experiment.

LINGO will be controlled by instructions written by the physicist in a language directly applicable to the data-handling and processing problems of bubble chamber physics. This will greatly aid his communication with the computer.

LINGO is being coded for the IBM 709 or 7090. Small sections will be written for the IBM 1401. It is being written in such a way that sections can be used by the physicist as they are written.

MISC

H4 and H5. These routines calculate four- and five-body phase-space distributions as functions of the effective masses of two of the particles. Additional features are being programmed to take into account resonance between various pairs of particles.

ORDLIST

This makes a summary listing and an ordered list from any tape of less than 5000 records in which each record is less than 1000 words. The routine is completely selective as to which records will be included in the summary.

ORBIT

This routine calculates space points defining the orbit of a particle in a magnetic field traveling through hydrogen. Given initial conditions (momentum vector, particle mass, and range) the program produces x, y, z coordinates of the orbit. This program is currently being modified to introduce multiple Coulomb scattering effects.

A program to perform path-length calculations was written for the low-energy K^- experiment.

This work was done by Benjamin F. Abington, Silverio P. Almeida, Graham H. Campbell, Lynn J. Champomier, Marcus Horovitz, Daphne Innes, David Johnson, Alice McMullen, Samuel J. Penny, Leonard Reed, Thomas C. Schneider, Cecil Tate, Hovan B. Zarian, and Robert J. Harvey for the Alvarez group.

B. Xenon Bubble Chamber Data Analysis

A package of 709 data-processing programs has been written in connection with experiments on K mesons in a xenon bubble chamber. They are as follows.

1. Data cards (produced by measurers from photographs of the bubble chamber) are read and real-space coordinates are calculated by the program STEREO. Certain validity and data-consistency checks are made.

2. FAST K. The incoming K meson undergoes a reaction

$$K^+ + n \rightarrow K^0 + p$$

and the K^0 quickly decays in either of two ways:

$$K^0 \rightarrow \pi^+ + \pi^- \qquad \text{(SPAGO)}$$

or

$$K^0 \rightarrow \pi^0 + \pi^0 \qquad \text{(NEUMOD)}$$

Each of the programs calculates angles, momenta, etc. and checks to see if the measured data are consistent with conservation laws for the given reaction. In addition, whenever a charged-pion decay is computed the data from that event are used in a Monte Carlo program (MCCAL) to generate a psuedo event of the type $K^0 \rightarrow \pi^0 + \pi^0$. These pseudo events are then used for comparison with experimental data. The use of the charged-pion decay data is one way of providing the proper phase-space distribution for the pseudo events.

3. SLO K. The incoming K is not scattered, but slows down and stops. The unstable particle then decays by one of six known decay modes. The purpose of the SLO K programs is to try to fit the measured data to one of the modes and thereby obtain relative probabilities of the decay modes. In addition to the six observed decay modes, there are other decay modes theoretically possible. Two of these are being programmed.

4. Random-Event Generators. Two programs have been written to "generate" random events which can be fed into the SLO K package, in order to test the ability of SLO K to distinguish between the two decay modes

FAKEV for $K^+ \rightarrow \pi^+ + \pi^0$; $\pi^0 \rightarrow 2\gamma$

and

3-BODY DECAY, which generates a random three-body decay (masses specified).

(Samual Howry, William Benson, and Gordon Sutherland for John Brown, John Kadyk, and George Trilling of the Glaser group.)

In one method of measuring the $K_1 - K_2$ mass difference, a K^0 beam is produced in the liquid of a bubble chamber by charge exchanges in a beam of fast K^+ mesons. According to the particle-mixture theory of the K^0 meson, the K^0 beam, which initially contains only positive-strangeness particles, gains through the K_1 decay a negative-strangeness component, which is capable of producing hyperons in the liquid. The mass difference is determined by measuring the time rate of change of this negative component. The actual method requires measuring the space distribution of hyperons produced by K^0's in flight. To change this space distribution into a time distribution that can be compared with the theoretical prediction, the momentum of the K^0 beam must be measured. Since the K^0 momentum is not unique, an average momentum spectrum must be measured and folded into the time distribution in order to predict the experimentally expected spatial distribution of hyperons. A 704 program was written to fold a variety of experimentally interesting momentum distributions into the theoretical time behavior of the K^0 mesons in order to obtain curves which can be compared with the experimental measurements. (Ed Towster for Don Glaser)

C. Additional Bubble Chamber Analysis

Several programs have been written for the 704 and 709 to do phase-shift error analysis. Given a minimum χ^2 of experimental and theoretical cross sections in elementary-particle interactions, various contours around the minimum are found, the shape of which gives the error in the phase shifts and hence the error in the experimental cross sections. The program will handle up to a five-dimensional space.

A program was written for the 704 which does kinematical transformations from the c.m. system to the lab system for an arbitrary reaction $A + B \rightarrow C + D$, and calculates total cross sections of $K^+ + d \rightarrow K^+ + d$ (elastic) and $K^+ + d \rightarrow K^+ + p + n$ (inelastic) with given phase shifts. (Marjory C. Simmons for Sulamith Goldhaber and Gerson Goldhaber)

A general-purpose phase-shift analysis program was written for the 704 or 709. By analysis is meant the following: a χ^2 function is defined in terms of parameters which are related to the phase shifts and "intervals of $\cos\theta$." A set of random values is then chosen for the parameters and the program proceeds to find a minimum by using the gradient method.

The program is subroutinized in such a way that it is a simple matter to define χ^2 surfaces: i.e., it is amenable to the treatment of experimental data, especially scattering, whose interpretations differ in particulars.

The program was also designed to handle the possibility of an analysis of several scattering experiments simultaneously, i.e., data collected at different incident energies and in which the energetically individual sets of phase shifts are related parametrically through the effective-range formalism.

The incorporation of the error matrices corresponding to the obtained minima is now being planned.

Calculations of various integrals and the evaluation of differential cross sections related to the K^+ - deuterium bubble chamber experiment were programmed for the 704.

A 704 program which prepares momentum path-length histograms using the output of the PATH program was written. The PATH program determines the total path length of a bubble chamber particle which lies within some arbitrarily defined volume. Using the initial momentum as stated in the output of PATH, the program LONG-COUNT determines the total length traversed during a particle's existence in certain momentum ranges.

A 709 program is being written which will compute the orbit of a particle in a bubble chamber. (Donald Itzel for Sulamith Goldhaber and Gerson Goldhaber)

A set of programs has been written which will test the output from the Hough-Powell (H-P) device for automatic scanning of bubble chamber film. The data from the device will be transmitted via the Direct Data Entry. A majority of the programs will be implemented later into the FOG-CLOUDY-FAIR system. (Donald Zurlinden for Howard White, Powell group)

D. Segrè Group

Several IBM 709 programs were written to calculate $\frac{d\sigma}{d\Omega}$ for various reactions, using data from the dish scintillation counter of the Segrè group. The reactions considered were
$\pi + p \rightarrow N + \pi + \pi$, $\pi + p \rightarrow \pi + p$, and $p + p \rightarrow N + \pi + p$.

A 709 program was written to calculate $\frac{dN}{dP_3}$ for the process

$P_5 + P_4 \rightarrow P_3 + P_2 + P_1$, where

$$N = \int \frac{d^3P_1}{E_1} \frac{d^3P_2}{E_2} \frac{d^3P_3}{E_3} \delta (\vec{P}_1 + \vec{P}_2 + \vec{P}_3 - \vec{P}_4 - \vec{P}_5) .$$

This is being used for a study of the π-π interaction in the process $p + d \rightarrow H_3 + 2\pi$.

A general-purpose search program was written for the 709 to find the minimum of a function of several variables. This routine will handle functions of n variables, where $n \leqslant 20$.

The 650 program KINE, which constructs tables of kinematical quantities for two-body reactions given the masses of the incoming and outgoing particles, was rewritten for the 709 and used extensively.

A 709 program was written to fold counter resolution characteristics with histograms of data from mocked-up K-meson decays. The faked events were produced by a Monte Carlo program written by Gordon Sutherland (see above). The final results were compared with experimental observations by Carl M. Noble, Jr. (Joe Good, Joe Lack, and William Johnson for the Segrè group).

E. Accelerator Design

Work was continued on writing and improving the IBM 704 and 709 codes for computing optimal trim coil currents for the 88-inch cyclotron. New programs include codes to interpolate data for intermediate nonmeasured main-coil current settings, to use formulated trim-coil settings, and to make harmonic corrections on the measured field data. Revisions were made to provide a programmed phase shift and variable momentum.

By use of actual field measurements and formulated trim-coil effects, computations were made on the high-field data of both 12° mesh, 360° map and 3° mesh, 120° sector map. Low-field data with a 3° mesh, 120° map was also done. First phase calculations were performed at four other excitations on a 12° mesh, 360° map. An analysis was made of all corrected field values obtained. (Johathan Young and Ardith Kenney for Alper Garren, Theoretical Group)

A study was made of the disturbing influence on the cyclotron orbits of the presence of a first harmonic bump in the magnet field.

Computational studies were conducted by using an analytically induced first harmonic bump in the cyclotron field with the orbit code GOC.

The orbit code BOC was used to determine magnet parameters for a two-magnet extraction system for the Bevatron. Information was obtained to allow specification of details of design for the magnets, but more work is needed to determine optimum operating parameters.

The deflection code CYBOUT was used to determine the feasibility of using a single electric channel deflector to extract particles of varying masses and energies from the 88-inch cyclotron. Highest-energy protons and deuterons, because of their extreme trajectories, were used primarily in the work.

In each of the above studies various modifications and revisions of the codes were necessary. CYBOUT was modified to make the study of different channel shapes possible. GOC was modified to allow harmonic studies to be made and also to permit orbits to be computed in which particles were running toward the center of the cyclotron. (Herman Owens for Alper Garren, Theoretical Group)

In conjunction with accelerator design work, 650 programs were written for the magnet test group as follows.

Five programs were written for processing data taken during the full-scale 88-inch cyclotron magnetic measurements. These programs convert raw data to actual values, assemble and punch the information in desired formats, and compare field values azimuthally, radially, and sequentially in the order of taking the data.

Programs already written for the Magnet Test Group were studied and additions or changes (or both) were effected to make them compatible with current input data. (Herbert C. Albrecht for Joseph Dorst, Magnet Test Group)

A 709 program has been written which computes acceptance of a particle in any constant-gradient synchrotron at a point $P(\alpha, x)$, where α = initial angle upon entering a vacuum chamber, and x = initial radial coordinate.

There are three bounding conditions considered which limit the acceptance at any $P(\alpha, x)$:

(a) particles collide with the back of the inflector;

(b) a particle collides with the outer boundary;

(c) a particle gets lost because it is not captured in a stable rf phase.

Output for each $P(\alpha, x)$ is the range of acceptance. (Barbara Steinberg for Hermann Grunder, Mechanical Engineering)

F. Miscellaneous Physics Programs

A program has been written to calculate dispersion relations for torsional hydromagnetic waves in plasma. (Marjory C. Simmons for Alan DeSilva, Van Atta group)

Three IBM 650 programs, RECOIL I, RECOIL II, and RECOIL III, have been written for the calculation of the energy spectrum of neutrons to which a nuclear track emulsion has been exposed.

RECOIL I. The energy distribution of proton recoils N(E) in a hydrogenous substance which arises by elastic collision from a distribution of neutrons $N_0(E)$ is given by

$$N(E) = \int_{\infty}^{E} \frac{n\sigma(E)\, N_0(E)}{E} \, dE ,$$

where n is the proton density, $E < 20$ Mev, and $\sigma(E)$ is the neutron cross section of hydrogen. In such a substance the neutron distribution is given by

$$N_0(E) = - \frac{dN(E)}{dE} \cdot \frac{E}{n\sigma(E)} .$$

The purpose of RECOIL I is to calculate the proton recoil energy distribuion from the track lengths in an emulsion; then calculate the neutron spectrum from the proton spectrum.

RECOIL II. The purpose of this program is to calculate the neutron spectrum when the emulsion is exposed end-on. The energy Ep of the proton is determined from the track length, and the energy En of the neutron is calculated by

$$En = \frac{Ep}{\cos^2\theta} ,$$

where θ is the polar scattering angle.

RECOIL III. This program is for the purpose of calculating the low-energy region of a neutron energy spectrum. The method used is similar to that used in RECOIL I except that the proton recoil tracks are taken from a cylindrical volume.

709 programs have been written as follows.

RECOIL I - 709. This program is being written for the purpose of doing a RECOIL I - type calculation, and is near completion. (Carl Quong for Richard Lehman, Health Physics)

Two programs have been written for the IBM 709 which are concerned with radiation straggling of μ mesons in various materials. The first of these, LANDAU, computes the probability of energy loss of a particle

traversing a target of finite thickness. This probability is computed for different energy losses. The second program, UNMUON, fits a theoretical μ^+-decay energy spectrum to the experimental values. (Walter H. Hutchinson for Hans W. Kruger)

A 709 program was written to compute the probability with which a beam of K mesons, having been scattered by passing through an absorber (hydrogen or deuterium), will now be detected by a counter. The probability TC is given by

$$TC = C \int_{x_3}^{x_4} y \int_{x_1}^{x_2} e^{-1/2 \left\{(x/u)^2 + [(x-y)/v]^2\right\}} dx\, dy.$$

(Richard Cottle for Tin Maung, Thornton group)

A FORTRAN program for use with the 709 FORTRAN Monitor was written to solve the differential equation of motion for the expansion system of a 25-inch liquid hydrogen bubble chamber. Determining the expansion times over a range of operating conditions and for different dimensions of the system, the program facilitates optimization of the design parameters. (David F. Stevens for John Myall)

A FORTRAN program was written to calculate the recoil momentum distribution in electron triplet production (for a given photon energy and for an arbitrary number--between 2 and 50--of values of recoil momentum between given minimum and maximum values). (David F. Stevens for Robert Kenney, Helmholtz-Moyer Group)

A program for the 650 was written to calculate--by Simpson's integration--the decay-in-flight correction for K mesons. (David F. Stevens for Tin Maung, Thornton group)

A FORTRAN/FAP program is being written to integrate the bremsstrahlund cross section for either a circular or rectangular collimator (including thick-target corrections). (David F. Stevens for Donald McPherson, Helmholtz-Moyer Group)

Several programs were written for the IBM 650 and 709 for a research project dealing with the formulation of the cross sections for electromagnetic pion-pair production. The three main integrals calculated were

$$I_1 = \frac{\alpha}{8\pi^2} \frac{P_1 P_2}{k} \iint 1/q^4 T^2 (q^2, \Omega_2)\, d\Omega_2 ,$$

$$I_2 = \frac{\alpha}{8\pi^2} \frac{P_1 P_2}{k} \iint 1/q^4\, 2T \operatorname{Re} T'\, d\Omega_2 ,$$

$$I_3 = \frac{a}{8\pi^2} \frac{P_1 P_2}{k} \iint 1/q^4 (T')^2 \, d\Omega_2 ,$$

with various conditions on the limits, variables, and parameters. (Claudette Rugge for Yongduk Kim, Theoretical Group)

The PIEF program for solving the coupled nonlinear integral equations of the pion-pion interaction was converted from the 704 to the 709, and several changes were made to take into account additional physical effects. An initial parameter study of these solutions was completed and additional calculations are being planned. (Graham H. Campbell for Geoffrey Chew, Theoretical Group)

Eigenvalues and eigenfunctions were computed for some of the vibrational states of the molecular ions H_2^+, D_2^+, T_2^+, HD^+, HT^+, and DT^+. This work was done on the IBM 701 computer. (Victor Brady for John Hiskes)

Orbits of charged particles emerging from the magnetic field of the Bevatron were computed for several experiments. (Victor Brady for George Kalbfleisch and Harold Ticho, Alvarez Group)

Work has begun on a new 650 program to compute the orbits of charged particles leaving the Bevatron magnetic field. This new program is being designed to facilitate its use by experimentalists for the conditions of their experiment. (Victor Brady)

The program HYPERFINE 3 was translated from 704 machine language to FORTRAN language, and is operational with the FORTRAN monitor on the 709. The program calculates, for arbitrary hyperfine transitions, the magnetic dipole, electric quadrupole, and variables g_J and g_I, using a set of observational data in the form of frequency of observed resonance versus magnetic fields. From the final values of these variables, the energy levels and residuals are calculated for each datum. (Donald Zurlinden for Howard Shugart, Nierenberg Group)

A 709 program has been written which may be described as follows: Given a set of m half lives and n points (y_j, t_j) (counting rate, time) with associated uncertainties σ_j, a decay curve

$$y = \sum_{i=1}^{m} A_i e - \lambda_i t \; (\lambda_i = \frac{\ln 2}{(T_{1/2})_i})$$

is fitted to the observed data by a least-squares technique, yielding parameters $A_1 \cdots, A_m$ and associated errors $\Delta A_1, \cdots, \Delta Am$. A maximum of 25 sets of observation data may be given. Thus a set of parameters and uncertainties $\{A_{jk}, \Delta A_{jk}\}$ is obtained, where j refers to the input data set and k to the half life.

For each k (= 1, $\cdots$, m) specified during input, certain of the A_{jk} and ΔA_{jk} are used, together with given frequencies x_j, to fit a bell-shaped curve

$$A = \frac{D-C}{1 + \frac{4}{B^2}(x - H)^2} + C, \text{ where}$$

D = maximum height,

B = width of curve at half-maximum height,

H = frequency at which A = D,

C = background constant.

A least-squares method is used for this also.

Some modifications that will permit greater flexibility, such as allowing the program to determine the half lives and the number of terms in the decay curve, are being planned. (Barbara Steinberg for Howard Shugart, Nierenberg Group)

A 650 program was written which attempts to model the interrelated effects of successive diseases, chronological age, external environmental influences, and accidents upon the general health and life expectancy of humans and other biological organisms. (Richard Cottle for Roger Wallace, Health Physics)

Currently being debugged is a 709 program which will calculate the double-spectral function of a set of coupled integral equations resulting from applying unitarity considerations to the Mandelstam representation of the scattering amplitude arising from a potential (direct and exchange) as expressed by a superposition of Yukawa potentials. (Ed Towster for John M. Charap, Theoretical Group)

A 650 program was written which calculated the radiation straggling functions for the electron-positron pair and computes the folded integral, as an aid in determining the resolution function for a γ-ray pair spectrometer. (Ed Towster for Jim Ryan, Thornton Group)

II. Chemistry

During this period the following projects were completed for use by the specified people in the Chemistry group.

A 709 FORTRAN and FAP program was written to process data recorded on magnetic tape from the Drum experiment, and assistance was provided in making several revisions to this program.

A 709 FORTRAN and FAP program was written to evaluate a multiple integral by a Monte Carlo calculation. This program included a subroutine for generating pseudo-random numbers.

A 709 FAP subroutine was written to allow magnetic tapes prepared by the paper-to-magnetic-tape converter to be read directly by the 709. This subroutine replaces one written for the 704 and is more efficient and contains more self-checking features than does the one for the 704. (Paul Concus for Stanley G. Thompson, Nuclear Chemistry)

A 709 FORTRAN and FAP program was written to process magnetic tapes prepared by the two-dimensional analyzer.

A 709 FORTRAN and FAP program was written as a revision of a 704 SAP program to compute the logarithm of the gamma function of complex argument. (Paul Concus for John Rasmussen, Nuclear Chemistry)

A 709 FORTRAN and FAP program was written to process magnetic tapes of a special type prepared by the two-dimensional analyzer and to perform a series of calculations with the data contained in the tapes. (Paul Concus for George Igo, Nuclear Chemistry)

A 709 FORTRAN program was written to compute polarization and cross-section data from theoretical formulae. (Paul Concus for Aharon Nir, Nuclear Chemistry)

In addition to completion of the above projects, there was assistance to various members of the Chemistry group in solving general computing and mathematical problems. (Paul Concus)

A program was written for fitting the best r_1 and r_2 to a number of observed values of I in the equation

$$I = \frac{m_1 m_2 r_1^2 + m_1 m_3 (r_1 + r_2)^2 + m_2 m_3 r_2^2}{m_1 + m_2 + m_3},$$

where m_1, m_2 and m_3 change but are known constants. (Herbert C. Albrecht for Dudley Hershbach, Chemistry)

A program was written to compute the integral

$$y = \int_{x_0}^{x} \log (A + \alpha B t^{-0.42})\, dt$$ within any specified accuracy limit.

(Herbert C. Albrecht for Terence Gooding, Nuclear Chemistry)

An IBM 709 program was written which fits a set of points to a straight line by using the method of least squares, in connection with alpha-decay barrier penetrabilities with an exponential nuclear potential, over a range of nuclei with a common atomic number. (Claudette Rugge for John Rasmussen, Nuclear Chemistry)

An IBM 704 program was written to fit the curve $\rho(v) = \rho_1(v) + \rho_2(v)$,

where $\rho_i(v) = \gamma_i \frac{a^2}{2\pi} v_i \left[\frac{\alpha}{T_1} e^{\frac{-bi}{T_1}} + \frac{1-\alpha}{T_2} e^{-b^2 i/T_2} \right]$, $b_i = av_i^2$,

$$v_1^2 = v^2 + v_L^2 - 2vv_L \cos\theta ,$$

$$v_2^2 = v^2 + v_H^2 + 2vv_H \cos\theta ,$$

where V_L, V_H, a, θ are input constants, and α, T_1, T_2, ν_1, ν_2 are unknown parameters. This was accomplished by using a subroutine which solves the nonlinear least-squares problem by using Gauss's Method. (Claudette Rugge)

In the determination of molecular structures, it is necessary to make allowance for the effects of vibration-rotation interaction in order to take full advantage of the extremely accurate moments of inertia obtained from microwave and infrared spectroscopy. This requires that a normal coordinate treatment of the vibrations be made for each isotopic molecule considered. A 650 program was written which does this for linear triatomic molecules. (Ed Towster for Victor Laurie and Dudley Hershbach, Chemistry)

A 704 program to minimize functions of the form $\Sigma(x_i - y_i)^2$, where the x_i are functions of several variables and the y_i are constants, is being debugged. (Thomas Clements for John Conway, Nuclear Chemistry)

A 704 program has been written following the suggestion of Dostrovsky et al. for a Monte Carlo model for nuclear evaporation.[1]

The program, starting with a given compound nucleus and excitation energy, generates a specified number of decay chains which are stored on tape. These tapes may then be processed by a second program and the final output consists of distributions of residual nuclei and emitted particles, and their respective energies, recoil velocities, and other data. Modifications are being contemplated which should improve the model in the above paper. (Samuel Howry for John Alexander, Nuclear Chemistry)

[1] I. Dostrovsky, Z. Fraenkel, and G. Friedlander, Monte Carlo Calculation of Nuclear Evaporation Processes. III, Phys. Rev. 116, 683 (1959).

III. Mathematics and Computing

The following work has been done to prepare general-utility programs for the use of the laboratory.

A FORTRAN-FAP program was written to automatically enter corrections into the SHARE catalogue.

A FORTRAN sampler was devised to give a sample compilation of every kind of statement possible in 709 FORTRAN.

The SHARE routine ZO AN Z013 (variable metric minimization) was converted from 704 FORTRAN to 709 FORTRAN for use with the 709 FORTRAN monitor.

A FORTRAN program was written to calculate the Bessel functions $I_0(x)$ and $I_1(x)$, for $x \geqslant 10$.

A FORTRAN program was written to calculate the Bessel functions $K_0(x)$ and $K_1(x)$, for $x \geqslant 1$. (David Stevens and Harold Hanerfeld)

A series of 704 SAP library subroutines has been converted into 709 SOS subroutines for use by the computing group. (Edna Williams and Harold Hanerfeld)

General-purpose Simpson integration subroutines (in FAP language for FORTRAN programs) were written. (Richard Cottle and Harold Hanerfeld)

Simulation and general-service routines are being prepared for use on the IBM 1401 upon its arrival. The simulation routines will enable the computing center to convert data from one physical carrier to another with greater efficiency than before. (Walter H. Hutchinson and James Baker)

The 650 FORTRAN system was studied and made operational. A 533 control panel was wired, existing 650 subroutines were studied and converted for use in the 650 FORTRAN system, instructions for using the subroutines and FORTRAN system were formulated and written, and new routines essential for adding subroutines to the FORTRAN system were written. All phases of 650 FORTRAN were tested, and each subroutine was tested before it was included in the 650 FORTRAN LIBRARY. (Herbert C. Albrecht)

By use of the IBM 650 time log and the IBM 704, 709 time cards, an IBM 650 program has been written which summarizes the monthly accounting for each machine according to account number and problem name. If, as in the case of the IBM 709, there are monthly time allotments for each account number, then the program will summarize as usual and, in addition, print out the amount of time left to be used or overdrawn by each account. (Claudette Rugge)

The 650 program library has been reorganized and expanded. New routines and adequate write-ups for all our subroutines are now readily available.

The program library catalogue (SHARE distributed programs) for the "700" machines and the 1401 has continued to grow. To facilitate access to these programs, write-ups and program decks for most programs are available on a help-yourself basis.

The program library has also been made available as a repository for programs used to solve specific problems originating at the Laboratory. This will avoid duplication of effort and provide an adequate description for future reference to these programs. (Harold Hanerfeld)

IV. Computer Operations and Systems Programming

During the interval November 1, 1960 to April 30, 1961, the following operations and systems-programming activities took place in the Mathematics and Computing Group.

Operations

704

During this interval utilization of the IBM 704 at the Campus Computing Center continued at a rate of approximately 95 hours per week. This time was devoted almost exclusively to production, since very few new programs are being written for the 704.

It is expected that during the next interval 704 usage will remain at roughly the same level. However, increasing demands for computation from campus users will decrease the amount of 704 time available to the Laboratory in subsequent intervals.

650

The IBM 650 which is owned by the Laboratory was used at rates varying from 80 hours per week to 160 hours per week during this period. The 650 is maintained as a programmer-operated machine available on an open-shop basis. It is used, generally, for small problems for which rapid answers are required. Most programs for this machine are written by users.

The special-character device was installed on the 650 during this interval. This device is a prerequisite for use of the 650 version of the FORTRAN compiler.

It is expected that during June 1961 the 650 and its associated peripheral equipment will be moved from Bldg. 47 to Bldg. 70 Annex. This will be a much more convenient location for the physics and chemistry research groups who are the principal users of 650.

709

The IBM 709 computer which was accepted by the Laboratory in November 1960 has been utilized since on a 7-day-per-week 24-hours-per-day

basis. This machine is operated under a closed-shop system. The use of monitor systems is encouraged. These systems permit sequences of jobs to be stacked on a single input tape, and minimize the loss of computer time in making the transition from one job to another.

A computer operating staff for the 709 has been recruited and trained. This staff operates the computer on all problems submitted, plans the scheduling of machine time, and assists in the diagnosis of machine and programmer errors.

At the end of the past interval the demand for 709 computer time was at the rate of 205 hours per week. This is an excess of 55 hours per week over the 150 hours available after preventive maintenance and unscheduled maintenance have been subtracted. It is expected that this deficit will be made up by purchase of time from outside installations until additional computers are available at the Laboratory.

1401

An IBM 1401 computer is scheduled for delivery to the Laboratory in June or July 1961. This machine will be used as an input-output processor for the 709 and 7090 and for administrative data processing.

7090

It is hoped that toward the end of the next interval a 7090 computer will be delivered to the Laboratory under an educational-contribution agreement with IBM. This machine will carry a large share of the computing load generated by the development and use of advanced scanning and measuring systems in the Alvarez and Powell groups.

Systems Programming

During this interval the mathematics and computing group continued to provide services in the maintenance and modification of various programming systems. Principal activities in this area are listed below.

1. FORTRAN compiler and FORTRAN monitor. These systems were modified to meet the requirements of the Laboratory's computer-operating system. Machine time-accounting routines were added to the monitor to take advantage of the clock installed on the 709. Modifications originating at IBM were incorporated in the system. Consulting services were provided for many FORTRAN users.

2. SOS (Share Operating System). This powerful machine-language coding system was modified in a manner similar to the FORTRAN monitor. Many changes were incorporated, since the system was still, during this period, in field-test status.

3. 1401 Input-Output System. A system is being prepared to handle off-line data preparation and printing requirements generated by the 709 and 7090.

During the next interval work will be started on a file-processing system for the 709 and 7090. This system is to be used in connection with scientific data-processing projects. (James Baker, Douglas Brainard, Graham Campbell, Donald Zurlinden, and Walter Hutchinson)

PHYSICS RESEARCH

Edward J. Lofgren in charge

SEARCH FOR DIRAC MONOPOLES

Hugh Bradner

The Bevatron search for Dirac monopoles[1] was extended to higher energy by making runs on the CERN proton-synchrotron in cooperation with Professor Amaldi (Rome) and Dr. Hoffmann and Dr. Vanderhaeghe (CERN). The monopole mass limit can now be tentatively set at approximately 2.7 m_{proton}. Further examination of the nuclear-emulsion detectors is under way, and a thin-target arrangement is being prepared to maintain the monopoles at relativistic velocity all the way from the point of creation to the detector.

[1] Hugh Bradner and William M. Isbell, Search for Dirac Monopoles, Phys. Rev. 114, 603 (1959).

K-NUCLEON INTERACTION

Victor Cook, Jr., Bruce Cork, Denis Keefe, Leroy T. Kerth, Paul G. Murphy,* William A. Wenzel, and T.F. Zipf

Work continued at the Bevatron on the study of the K-nucleon interaction. Data from a new experiment on the K^+-nucleon interaction are under analysis. Results to date, show that the K^+-p and K^+-n total cross sections are about constant at 17 mb over the momentum range 0.8 to 2.9 Bev/c. These results apparently resolve a doubt about the high-energy behavior of the K^+-p cross section, for which previous measurements were in serious disagreement. Additional results of this experiment will be concerned with the angular distribution of K^+-p and π^+-p elastic scattering measured at several energies. These measurements were made by two methods. For small angles a counter hodoscope and magnetic spectrometer similar to that used in the earlier K^--p measurements were employed. For large angles three spark chambers were used. Preliminary results indicate that even at the lowest momentum, 1.0 Bev/c, a substantial deviation from the isotropy previously seen at lower energies appears in the angular distribution for K^+-p scattering.

Three members of the group--Denis Keefe, Leroy T. Kerth, and Theodore F. Zipf--participated in an experiment with the Chamberlain and Thornton groups during October and November to study the total cross sections for K^--p and K^--n reactions in the momentum region 600 to 1200 Mev/c. This region lay between those covered by the low-energy bubble chamber measurements and the high-energy results of Victor Cook et al. The

*On leave of absence from the Rutherford High Energy Laboratory, Harwell, England.

experiment was carried out with high momentum resolution (1 to 2%) and careful energy calibration, and showed the existence of strong structure effects in the K^- - p total cross section near 1050 Mev/c. Any structure in the K^- - n system was found to be very much smaller.

SPARK CHAMBER DEVELOPMENT

Bruce Cork, Paul G. Murphy,* C. M. P. Johnson,† Denis Keefe, L. J. Koester,‡ and William Wenzel

Considerable effort of the group has been placed upon the development of spark chambers. In addition to the K^+-p scattering experiment described above, spark chambers have been used to study the polarization of protons produced in high-energy reactions. This is done by studying the asymmetry of scattering in a chamber with graphite plates. Polarization of protons produced in π-p scattering from 600 to 900 Mev was measured at several angles.

Another spark chamber experiment now in progress is designed to measure the polarization of protons produced in Σ^+ and Λ^0 decay. This experiment can determine the sign of the asymmetry parameter, α, as well as the ratio of S wave to P wave in the decay.

*On leave of absence from the Rutherford High Energy Laboratory, Harwell, England.

†On leave of absence from the Clarendon Laboratory, Oxford, England.

‡On leave of absence from the University of Illinois, Urbana, Illinois.

K^+ - MESON INTERACTION IN HYDROGEN

Hugh Bradner, William Chinowsky,* Gerson Goldhaber,* Sulamith Goldhaber, and T. Stubbs*

(in collaboration with Harold K. Ticho and Donald Stork, UCLA)

The analysis of interactions of K^+ mesons in hydrogen at 812 Mev/c and 280 to 120 Mev/c has been completed.

A. At 812 Mev/c the cross section for elastic scattering is $\sigma_e = 13.0 \pm .7$ mb. The analysis of the elastic differential cross section in terms of S and P wave give the following sets of values for phase shifts.

*Segrè group.

Solution	Shift (in deg) σ_1	σ_{11}	σ_{13}	Probability from χ^2 fit (%)
A	-47 (±1.5)	0.5 (±5)	1 (±3)	15
B	±2 (±3)	∓46 (1.5)	∓1 (±2)	80
C	∓2 (±3)	∓14 (±2.5)	±29 (±1.5)	80

Inelastic pion production yields a cross section of 1.0 ± .2 mb. The three possible channels contributing to the inelastic pion production have the following relative intensities:

Channel	Relative Intensity
1. $K^+ + p \rightarrow K^0 + \pi^+ + p$	1
2. $K^+ + p \rightarrow K^+ + \pi^0 + p$	0.35
3. $K^+ + p \rightarrow K^+ + \pi^+ + n$	0.1

The inelastic pion production appears to be dominated by Channel 1. The data are now being examined for possible final-state interactions that would enhance this channel.

B. The scattering below 280 Mev/c has been divided into two momentum intervals, i.e., 280 to 220 Mev/c ($\overline{T}_K \doteq 58$ Mev) and 220 to 120 Mev/c ($\overline{T}_K = 33$ Mev). The nuclear part of the cross section was obtained by an analysis of the differential cross section in terms of the Coulomb scattering amplitude and S-wave amplitude. The rather strong energy dependence of the phase shifts cannot be fitted with a zero-effective-range theory. An attempt is being made to examine the differential cross section in smaller momentum intervals in order to shed further light on this problem.

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Sulamith Goldhaber, Gerson Goldhaber, Wilson M. Powell, and Rein Silberberg, Antiproton Annihilations in Propane, Phys. Rev. 121, 1525 (1961).

Gerson Goldhaber, Sulamith Goldhaber, and Bernard Peters, Separation of High-Energy Particles by Means of Strong Interaction Processes, Nuclear Phys. 23(1961).

Gerson Goldhaber and Sulamith Goldhaber, A Preliminary Study of Enriched High-Energy Antiproton Beams, SC Internal Report 60-13, CERN.

NEW EXPERIMENTS

Preparation is under way for two new experiments. One is intended to continue the study of the K^- - p interaction at low energies through scattering and total-cross-section measurements. For this work a cylindrical spark chamber is under development. Other measurements that can be made in this experimental setup are concerned with the polarization of recoil protons in K^- - p scattering and the excitation function of Ξ^- production in the K^- - p interaction.

The other experiment under preparation will measure the pion-pion cross section as a function of energy. This experiment requires the use of several spark chambers and a pion pair spectrometer.

Preparations are also being made for an experiment to measure the leptonic decay ratio of the Σ hyperons. This experiment will use a liquid hydrogen Cerenkov counter and a lead glass total-absorption spectrometer in addition to the more common detection devices. This experiment will be done in collaboration with the Chamberlain and Glaser groups from this Laboratory and Dr. C. M. York of UCLA.

ELECTRON LINEAR ACCELERATOR

William Everette

Work has continued on the 5-Mev electron linac at a constant pace since its installation in March 1956. During the past six months (November through April) the machine has been used primarily in the fields of organic and physical chemistry, soil sciences, and physics.

Dr. Amos Newton, Physical Chemistry, has a program going on, illustrating and comparing the reactions of high-energy electron radiolysis in vapor state and those of photolysis in vapor state. A subsequent development has been a means of determining lifetimes of radicals that formerly were impossible to detect alone. The technique depends on pulsed high-energy electron irradiations with a variable interpulse time. About 50% of the machine operating time was applied to this work.

Dr. M. Calvin, Organic Chemistry Department, U.C., continues to utilize the linac beam in a program of life-origin work. During this period, gaseous mixtures of methane, ammonia, and water vapor (which represent primitive atmospheres) were irradiated in the presence of phosphates, olivine, and other minerals (meteorites) which may have catalyzed the reaction that led through chemical evolution to the microbe (i.e., an organic structure). This work has been conducted by Christof Palm, a visiting scientist from the University of Munich. About 30% of the machine time has been used for this purpose.

In the realm of soil-science research, the electron beam is being uniquely applied in soil sterilizations. Soils irradiated to a few million rep are rendered sterile in the sense that microbes within the soil are no longer able to reproduce. These soils are then used in studies of plant growth under ideal conditions. This technique is desirable since the soil is left in a more natural state than it would be after sterilization by autoclave or by the addition of chemicals. This work is conducted by Dr. McLaren of the U.C. Soil Science Department under an AEC grant. About 10% of the machine time has been used for this work.

Further application of the electron beam has been the determination of radiation damage rates to scintillation materials, solid-state electronic devices, and other target materials used in nuclear bombardments at the larger accelerator installations. Tests and calibrations of some particle detectors--e.g., the Cerenkov and coincidence phototube--which would normally be done at the cylotron or Bevatron have been made in the linac beam. Although this technique is desirable for economy reasons, it has been hampered by a slightly low beam energy. Thus, for this and other reasons, plans are currently being made to increase the electron energy. Dr. Wade Patterson, of Health Physics, expects to use 7- to 10-Mev electrons for fission-foil calibrations; neutron production will be possible. High penetrating power is desired in the soil sterilization work. Many further applications will become apparent as the program continues.

An increase in energy to 15 to 20 Mev is possible by using higher rf power with our present accelerator sections. No modification of the existing circuitry will be necessary except for the klystron pulse power transformer. A lower transformer-turns ratio will be used to match the impedance of the 5-megawattt klystron to the pulse-line impedance presently used for the 1.3-Mw tube. The higher-power S-band tubes are now available from at least three sources.

PHYSICS RESEARCH

Burton J. Moyer and A. C. Helmholz in charge

PRIMARY COSMIC RAY STUDIES

Selig N. Kaplan

The Laboratory has been invited to participate in a space research project by making measurements of primary cosmic radiation from an artificial satellite. The project is being supervised by Convair Astronautics for ARPA (Advanced Environmental Test Satellite). The satellite is to be launched sometime in 1962 into a circular orbit at an altitude of 24,000 miles. At this altitude it will have a 24-hour period. The purpose of the satellite is to monitor the physical environment at this altitude for at least 6 months in preparation for the later launching of communications satellites into similar orbits.

The instrument we are constructing is a simple telescope consisting of a Cerenkov radiator sandwiched between two plastic scintillators. It will have two energy thresholds; one determined by proton range in the telescope (nominally 150 Mev) and the other determined by the Cerenkov threshold (nominally 500 Mev). In addition, two Cerenkov pulse-height thresholds will be distinguished; one corresponding to $Z \geqslant 1$ and the other to $Z \geqslant 2$.

The design and construction of this device presents a challenging technical problem. The complete package will consist primarily of the detectors, power supplies, coincidence circuits, several rate meters, and 36 binary scaling pairs. It is subject to a weight limit of 15 lb and a maximum power consumption of 2 watts. It must withstand the mechanical and thermal shocks of the rocket flight and then operate reliably for at least 6 months.

At present the basic structural design has been completed and the electronic circuits have been designed and are being tested. The details of the mechanical assembly and a number of potential components--for example, the phototubes--are still under evaluation.

The specialized electronics required is being designed by an engineering group under the leadership of Frank Evans. Lee Glasgow is the mechanical engineer designing the package, and Philip Ogden is the principal graduate student working on the experiment.

STUDIES ON μ^- MESONS

Selig N. Kaplan, Robert V. Pyle, Justo Diaz, Jagdish S. Baijal, Gabriel Kojoian, and Burns Macdonald

In connection with the experimental study of the Fermi-Teller Z law, the disappearance rates of μ^- mesons in several elements have been carefully measured. The results are as follows.

Element	τ (nsec)	Element	τ(nsec)
S	484 ± 16	Sb	91.5 ± 1.4
Fe	196.2 ± 2.5	Au	68.6 ± 1.3
Cu	161.9 ± 1.9	Pb	73.9 ± 1.0
Ag	84.4 ± 1.0		

Most of these measuremtns are considerably more accurate than previously published work on the μ-meson β decay, since the method here used (detection of neutrons from the nuclear interaction) is comparatively free from background, particularly for medium and heavy nuclei. The reduction of the data from the Z-law study, being done primarily by Jagdish Baijal and Gabriel Kojoian, is nearing completion.

A short experiment is about to begin at the 184-inch cyclotron to investigate nonradiative atomic transitions (2P-IS) of μ^- mesons. The probability of such transitions was calculated by Zaretsky, who predicted they should compete favorably with x-ray emission in heavy elements. He further predicted that the energy evolved would be absorbed by the nucleus, giving rise, very possibly, to nuclear fission (the least ambiguous and most easily observed form of nuclear de-excitation). We have previously looked for fission of natural U in prompt coincidence with a stopping muon, and have shown that such a reaction occurs infrequently, if at all.

Recently these nonradiative transitions have been observed indirectly by Blatz et al.[1] and by Hinks et al.,[2] both of whom observed a reduced intensity of K-mesonic x rays from muons in U.

In view of these results we are repeating our previous experiment, using as targets U^{235} and Th, in both of which nuclear fission as a channel for de-excitation competes more favorably with neutron emission than it does in U^{238}.

The graduate student principally concerned with this fission experiment is Justo Diaz.

[1] M. J. Blatz, L. N. Kondratiev, L. G. Landsberg, P. I. Lebedev, Yu. V. Obukov, and B. Pontecorvo, Reprint R-448, Joint Institute for Nuclear Research, Dubna, 1959.

[2] E. P. Hinks, C. S. Johnson, and H. L. Anderson, University of Chicago Preprint of Abstract Submitted to Canadian Association of Physicists International Conference on Nuclear Structure, Kingston, Canada, Aug. 1960.

PION PRODUCTION BY PIONS INCIDENT ON PROTONS

Barry C. Barish, Richard Kurz, and Julius Solomon

The reaction $\pi^- + p \rightarrow \pi^- + \pi^+ + n$ has been studied by observing the energy and angular distribution of the π^+. Final corrections have now been applied to these data. The results have been published.[1] The influence of the 3,3 pion-nucleon resonance was noted in the data.

A preliminary measurement of the total cross section for $\pi^- + p \rightarrow \pi^- + \pi^0 + p$ at 310 Mev has been made. This was done by observing the inelastic proton at various angles and energies. The inelastic proton was separated from other particles by a combination of dE/dX, stopping, and time-of-flight techniques. More extensive measurements of this mode are planned during summer 1961.

[1] Barry C. Barish, Richard J. Kurz, Paul G. McManigal, Victor Perez-Mendez, and Julius Solomon, Phys. Rev. Letters 6, 297 (1961).

TEST OF CHARGE INDEPENDENCE

John A. Poirier, Morris Pripstein, William Bowman, and Jim C. Carroll

The experiment consisted in looking for the reaction $d + d \rightarrow He^4 + \pi^0$, which is forbidden if isotopic spin is conserved. The experiment was carried out with a beam of deuterons of 460 Mev kinetic energy (lab). The target was high-pressure deuterium gas at liquid nitrogen temperature. The experiment has been completed and a preliminary analysis has been made. A null result was obtained; a limit for the cross section corresponding to a 2-standard-deviation stretch of the data is

$$\frac{d\sigma_{c.m.}}{d\Omega} \quad (\theta_{c.m.} = 90 \text{ deg}) \leq 23 \times 10^{-34} \text{ cm}^2/\text{sr}.$$

This limit, together with a theoretical calculation by Kenneth Greider, places a limit of 6.5% on the amount of nonconservation of isotopic spin. Results of this experiment and the theory will be published in two papers.[1,2]

[1] Kenneth Greider, Phys. Rev. 122, 1919 (1961).

[2] John A. Poirier and Morris Pripstein, Phys. Rev. 122, 1917 (1961).

PHOTOPION PRODUCTION FROM HYDROGEN

Donald A. McPherson and Robert W. Kenney

A preliminary result has been obtained for this experiment, which was done in July 1959 with the Alvarez 4-inch liquid hydrogen bubble chamber and the electron synchrotron. A complete analysis of 2% of the data resulted in a differential cross section of 4 ± 1 μb/sr at a gamma-ray energy (lab) of 160 Mev. This is in good agreement with theory and previous experiments. The remaining data will be analyzed as soon as a new film-measuring machine is finished.

In conjunction with this experiment, an IBM 709 program is being written to calculate the synchrotron energy spectrum by using the new bremsstrahlung cross sections of Olsen and Maximon.

PHASE-SHIFT COMPUTER PROGRAMS

Paul McManigal, Robert Cence, and Donald Hagge

A IBM 709 computer program has been developed to solve for phase shifts in pion-proton scatterings.

Differential scattering data, total cross section, polarization measurements, and initial values of the phase shifts are given to the program, and the error between the calculated and the experimental values computed. Phase shifts are adjusted by the computer to minimize this error.

Many sets of phase shifts are possible in the region 500 to 1000 Mev with present data. Several methods of arriving at solutions can be employed with the existing program. Both the grid and the gradient methods can be used to seek a minimum error. A ravine method which plots out valleys of solutions can also be employed.

Greater use can be made of these programs when more experimental data have been obtained, and it is hoped that a unique set of phase shifts can be identified, or at least that the possible number may be reduced to a very few.

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

Robert J. Cence, Gilbert Mead, Don Lind, and Paul McManigal

A cyclotron run has just been completed in which energy of spectra of gamma rays from neutral mesons produced in proton-proton collisions at 730 Mev were measured at three selected angles. These angles were 14, 55, and 90 deg in the center-of-momentum system of the two protons.

Preliminary results agree roughly with the results of an earlier cyclotron run described in the preceding semiannual report.

The problem of multiple response among the channels of the pair spectrometer (mentioned in that report) was successfully eliminated by the use of "circular" geometry in the pair spectrometer. See Fig. 1.

The distortion of the low-energy end of the spectrum was reduced considerably, partially by more careful collimation and partially by the use of anticoincidence counters placed before the converter of the pair spectrometer.

The electronics of the counting system was coupled to an IBM card punch in such a manner as to give the data directly in a form to be fed to the 709 computer. The latter, in turn, was provided with a calculational program and data which permitted it to make all systematic corrections to the data and compute the final datum points ready for plotting.

Results will be published as soon as detailed analysis of the data has been made.

π^--p ELASTIC SCATTERING AT 550, 600, 720, 900, AND 1020 Mev

Calvin D. Wood, Thomas J. Devlin, Jerome A. Helland,
Michael J. Longo, Burton J. Moyer, and Victor Perez-Mendez

This report contains the results of measurements of differential cross sections taken in the energy region of the second and third peaks of the π^--p total scattering cross section.[1,2] The data were obtained by using an array of recoil proton scintillation counters in coincidence with pion detectors to identify elastic events. Descriptions of the experimental procedure and the data analysis have been previously reported.[3]

It should be here stated that we were unable to arrive at an independent normalization for the data, because of difficulties in monitoring the pion beam, although the shapes of the curves were rather well determined and repeatable. Therefore, we normalized our data to the total elastic cross sections as determined by other workers and summarized by Falk-Vairant,[4] keeping the point at $\cos\theta^* = 1$ fixed at the value determined by dispersion relations[5] and the optical theorem (where θ^* is the c.m. scattering angle for the pion). Hence, the normalization is known only to about ±12 to 15%. A future run is planned to measure the absolute normalization.

[1] J.C. Brisson, J. Detoef, P. Falk-Vairant, L. Van Rossum, G. Valladas, and L C.L. Yuan, Phys. Rev. Letters 3, 561 (1959). Also see their report in Proceedings of the 1960 Annual International Conference on High-Energy Physics at Rochester (Interscience Publishers Inc., New York, 1960).
[2] T. J. Devlin, B.C. Barish, W.N. Hess, V. Perez-Mendez, and J. Solomon, Phys. Rev. Letters 4, 242 (1960).
[3] Previous semiannual report; also C.D. Wood, T.J. Devlin, J.A. Helland, M.J. Longo, B.J. Moyer, and V. Perez-Mendez, π^--p Elastic Scattering at 550, 600, 720, 900, and 1020 Mev, to be submitted to Phys. Rev.
[4] P. Falk-Vairant and G. Valladas, in Proceedings of the 1960 Annual International Conference on High-Energy Physics at Rochester (Interscience Publishers, Inc., New York, 1960), p. 38.
[5] J.W. Cronin, Phys. Rev. 118, 824 (1960).

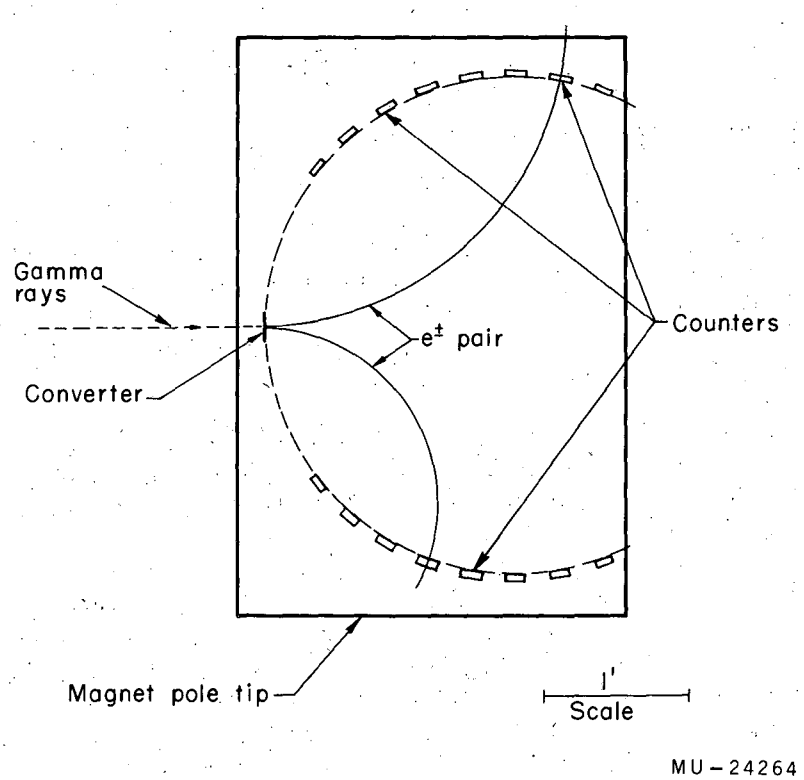

Fig. 1. Circular pair spectrometer (top view).

The errors quoted were obtained from a statistical analysis of the reproducibility of repeated runs. The only region of the curve where the errors are significantly different from pure statistics (i.e., different by more than a factor of two) is that in which the recoil proton had nearly the same laboratory-system angle as the scattered pion. Corrections due to accidental and inelastic counts were 2% or less for all channels and all energies.

The results are listed in Table I, where θ^* is the c.m. angle of the scattered pion and $\frac{d\sigma}{d\Omega}$ is the differential cross section (in mb/sr). The corresponding graphs appear in Fig. 2.

In Fig. 3 we present a plot of the energy dependence of the coefficients of the various cosine power series adjusted to our data, and also to the data of Goodwin et al.,[6] Shonle,[7] Bergia et al.,[8] and Chrétien et al.[9] The initials standing by the data points indicate their origins. From this behavior of the coefficients we make the following inferences.

1. The prominence of a_3 between 300 and 550 Mev may be ascribed to P-D interference. If so, it may be due to the overlap of the high-energy tail of the 200-Mev $P_{3/2}$ resonance with a D-state interaction building up with increasing energy.

2. The small magnitudes of a_3 and a_4 at 600 Mev indicate that if a D-state interaction exists at 600 Mev it has angular momentum 3/2. If at 600 Mev no states higher than $D_{3/2}$ interact strongly, and if the $P_{3/2}$ interaction has sufficiently decreased, we can understand the small $\cos^3\theta$ and $\cos^4\theta$ contributions and the prominence of a_2; a superposition of principally $S_{1/2}$ and $D_{3/2}$ waves would give just this.

3. At 900 Mev we require strong values of a_3, a_4, and a_5; but no powers higher than $\cos^5\theta$ are required to fit the data. These facts call for a prominent $F_{5/2}$ interaction together with strong D-state interaction. We cannot fit the 900-Mev data without a superposition of F and D waves (and possibly of P waves as well). The hump in the vicinity of $\cos^* = 0.8$, which appears to be at a maximum at 900 Mev, is due to D and F (and possibly also P) spin-flip amplitudes in superposition.

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[6] L. K. Goodwin, R. W. Kenney, and V. Perez-Mendez, Phys. Rev. Letters 3, 522 (1959); also The Elastic Scattering of Negative Pions by Protons at 230, 290, 370, and 427 Mev, Phys. Rev. (in press).

[7] J. I. Shonle, Phys. Rev. Letters 5, 156 (1960).

[8] S. Bergia, L. Bertocchi, V. Borelli, G. Brautti, L. Chersovani, L. Lavatelli, A. Minguzzi-Ranzi, R. Tosi, P. Waloschek, and V. Zoboli, Nuovo cimento 15, 551 (1960).

[9] M. Chrétien, J. Leitner, N. P. Samios, M. Schwarz, and J. Steinberger, Phys. Rev. 108, 383 (1957).

Table I. Angular distribution from $\pi^- + p \rightarrow \pi^- + p$. The normalization of the curves is known only to within about 12 to 15% (see text for explanation).

E = 550 Mev		E = 600 Mev		E = 720 Mev		E = 900 Mev		E = 1020 Mev	
Cos θ^*	$d\sigma/d\Omega^*$ (mb/sr)	Cos θ^*	$d\sigma/d\Omega^*$ (mb/sr)	Cos θ^*	$d\sigma/d\Omega^*$ (mb/sr)	Cos θ^*	$d\sigma/d\Omega^*$ (mb/sr)	Cos θ^*	$d\sigma/d\Omega^*$ (mb/sr)
1.0	4.65 ± .24	1.0	6.19 ± .21	1.0	5.46 ± .24	1.0	17.82 ± .56	1.0	12.91 ± .40
0.62	2.63 ± .14	0.60	2.69 ± .05	0.57	1.44 ± .032	0.78	3.92 ± .050	0.76	3.00 ± .064
0.54	2.16 ± .08	0.52	2.29 ± .035	0.49	1.17 ± .034	0.53	0.405 ± .017	0.50	0.345 ± .019
0.37	1.74 ± .16	0.35	1.54 ± .27	0.31	0.86 ± .22	0.44	0.203 ± .027	0.41	0.200 ± .034
0.16	1.16 ± .20	0.14	0.79 ± .11	0.10	0.717 ± .095	0.25	0.218 ± .063	0.22	0.204 ± .046
0.02	0.577 ± .040	0.00	0.332 ± .021	-0.04	0.302 ± .017	0.03	0.273 ± .026	0.00	0.365 ± .025
-0.10	0.302 ± .028	-0.12	0.167 ± .013	-0.17	0.308 ± .014	-0.10	0.351 ± .022	-0.14	0.351 ± .035
-0.24	0.172 ± .028	-0.26	0.124 ± .013	-0.31	0.438 ± .034	-0.23	0.461 ± .019	-0.26	0.392 ± .022
-0.45	0.230 ± .023	-0.46	0.254 ± .017	-0.50	0.780 ± .029	-0.36	0.726 ± .022	-0.39	0.441 ± .026
-0.66	0.730 ± .043	-0.68	0.674 ± .023	-0.70	1.13 ± .023	-0.54	1.409 ± .031	-0.57	0.745 ± .050
-0.78	1.13 ± .05	-0.79	0.911 ± .030	-0.81	1.09 ± .027	-0.73	2.069 ± .034	-0.75	1.102 ± .044
-0.87	1.41 ± .06	-0.88	1.20 ± .046	-0.89	0.985 ± .042	-0.83	2.019 ± .044	-0.84	1.030 ± .043
-0.94	1.53 ± .15	-0.94	1.27 ± .055	-0.95	0.550 ± .068	-0.90	1.635 ± .046	-0.90	0.792 ± .043
						-0.95	0.790 ± .049	-0.96	0.297 ± .041

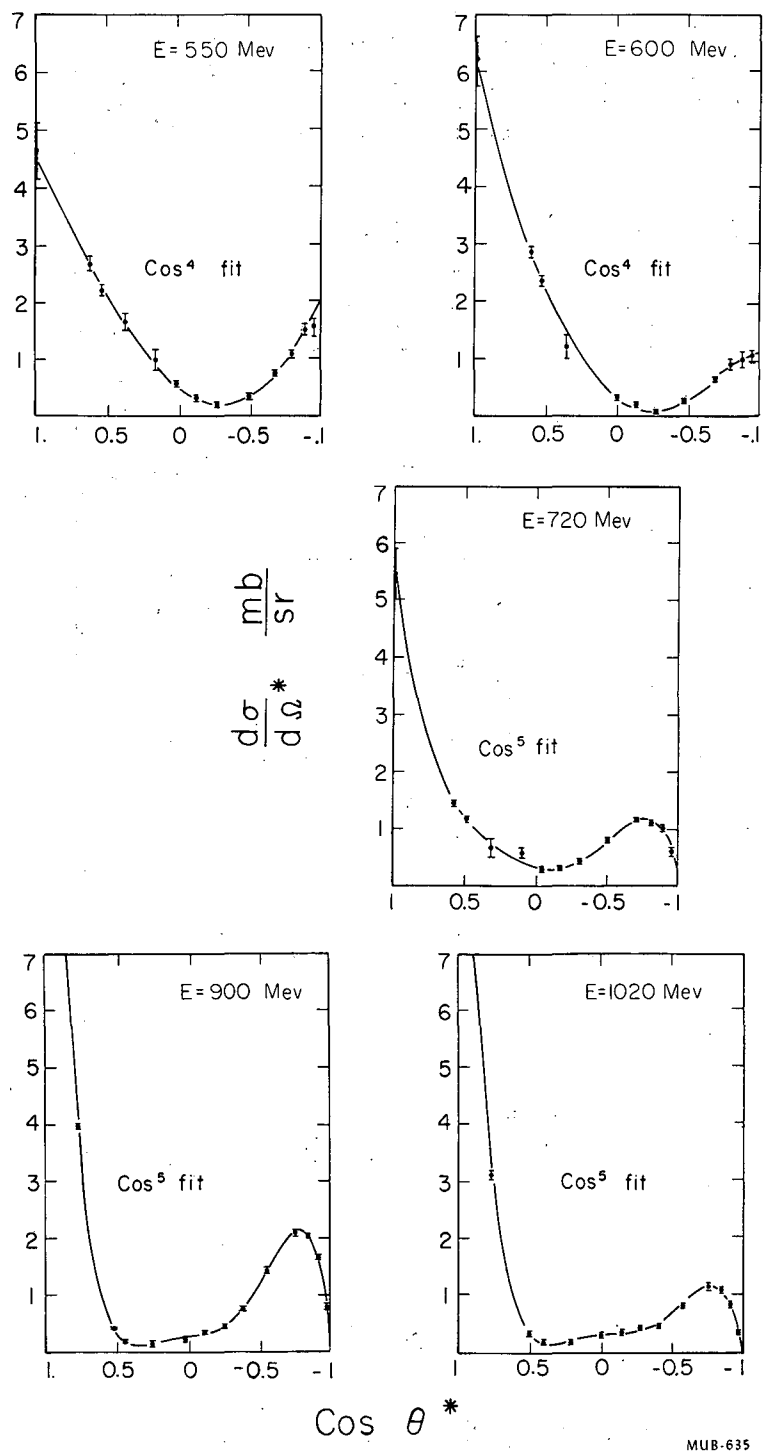

Fig. 2. Angular distributions from $\pi^- + p \rightarrow \pi^- + p$; θ^* is the angle by which the pion is scattered in the c.m. system. The solid curves were obtained from a least-squares fit of a cosine power series to the data.

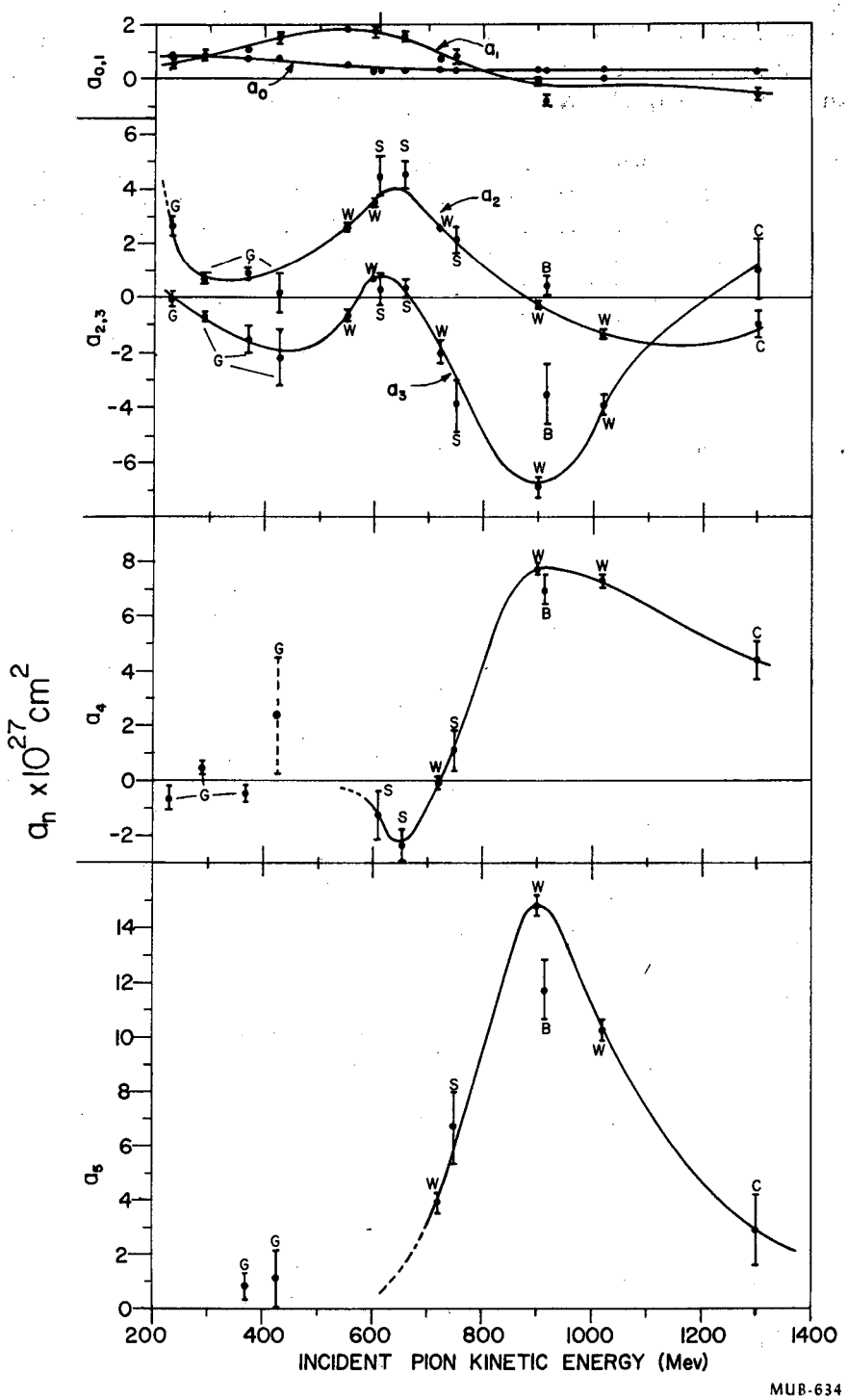

Fig. 3. Coefficients a_ℓ from the expansion $d\sigma/d\Omega^* = \sum_{\ell=0}^{\ell_{max}} a_\ell \cos^\ell \theta^*$, which was fitted to the data by the method of least squares.

4. The strong forward peaking, particularly at 900 Mev, implies that absorptive processes may be prominent in these "resonances." At 900 Mev a simple diffraction model with an absorbing volume whose radius is 1.2 fermis can describe quite well the small-angle data.

More extensive analysis of these results is in progress, including phase-shift calculations, and further experimental work is planned, including polarization measurements. In agreement with the assignments of Peierls,[10] we infer strong $D_{3/2}$ interaction at 600 Mev, and strong $F_{5/2}$ interaction at 900 Mev; but our data indicate a more complicated picture than simple resonances in these states.

[10] R.F. Peierls, Phys. Rev. 118, 325 (1960).

PHYSICS RESEARCH

Wilson M. Powell and Robert W. Birge*

INTERACTION STUDIES

Decay Asymmetry of the Ξ^-

Robert W. Birge* and Robert Ely

Eighteen Ξ^- decays produced by 1.15-Bev/c K^- mesons, reported previously, have been used to determine the product $\alpha_\Lambda \alpha_{\Xi^-} = -0.65 \pm .35$, where α is the decay asymmetry parameter associated with the nonconservation of parity in weak decays. The negative sign indicates that the helicity of the Ξ^- decay is opposite that of the Λ (which Robert W. Birge and William B. Fowler have determined to be negative). Since the magnitude of α_Λ is thought to be greater than 0.95 (Frank S. Crawford, Lawrence Radiation Laboratory, private communication), we find $\alpha_{\Xi^-} = 0.69 \pm .36$.

Elastic π^+ - p Scattering

Peter Newcomb

A total of 2,400 events have been measured from 20,000 pictures taken in the 15-inch hydrogen chamber with 750-Mev/c π^+ mesons. The FOG program has been modified and remeasures are nearing completion.

Pion-Pion Interactions

Zaven Guiragossian

Measurements are completed and analysis proceeds on 5,000 two-prong events of the type

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

$$\pi^- + p \rightarrow \pi^- + \pi^+ + N + n\,(\pi^0),$$

$$\pi^- + p \rightarrow \pi^- + p + n\,(\pi^0)$$

produced by 3-Bev/c π^- mesons in the 72-inch hydrogen chamber. A study of errors in the chamber is in progress.

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*On leave of absence at the Laboratoire de Physique, École Polytechnique, Paris.

Systematic Study of Interactions of 1.1-Bev/c K^- Mesons in Propane

Robert Ely, George Gidal, Sun-Yiu Fung, Yu-Li Pan, and Tom Schumann

A study of the reactions

$$K^- + p \rightarrow \Lambda + \pi^+ + \pi^- , \quad (1)$$

$$K^- + N \rightarrow \Lambda + \pi^- + \pi^0 \quad (2)$$

has been made. To date 40,750 pictures have been scanned; 1834 Λ two-prong events have been found of which 900 are $\Lambda_{\pi^+\pi^-}$. Results based on 203 events of Reaction (1), which meet the hydrogen constraints, show production of the pion-hyperon resonance (Y^*) with the following properties:

	No. of events	Mass	Γ
Y^{*-}	125	1388 ± 3	74 ± 5
$Y^{*\pm}$	78	1384 ± 4	45 ± 8

It was hoped that at this beam momemtum the Bose-statistics interference effects would be small,[1] so that an Adair analysis of the decay angular distributions would yield the spin of the Y^*. Such distributions using acceptance intervals of $|\cos\theta \text{ prod}| > 0.80$ and 0.85 indicate that some interference effects are still present. In addition, there is reason to believe that D waves are needed to explain the production angular distributions. In this case the acceptance interval must be drastically reduced and fewer events will be available for the Y^* spin determination.

K^+ - p Elastic Scattering

Warner Hirsch and George Gidal

Scanning has been completed for both elastic scatterings and secondary proton scatterings, yielding 5,700 two-prong events. Of these, 1,300 have second scatterings. Measurements are still in progress.

[1] R.H. Dalitz and Donald H. Miller, Phys. Rev. Letters 6, 562 (1961).

DATA ANALYSIS FOR THE 30-INCH PROPANE BUBBLE CHAMBER

Howard S. White

Program Development

During the 6-month period of this report, the FOG IV system has processed 30,000 events from the 30-inch propane bubble chamber, the 72-inch hydrogen bubble chamber, and the 15-inch hydrogen bubble chamber, giving angle and momentum descriptions of the tracks. This should be compared with the figure of 30,000 events processed during the year prior to this period. The increased efficiency is due to a gradual shift to the IBM 709 from the IBM 704 and also to a modification in the experiment libraries which decreases the length of the libraries to 1/3 their previous size and therefore proportionately decreases tape-handling time.

The FOG IV system is currently being modified to select the best two views from a three- or four-view system for the spatial reconstruction, using a secondary pair of views as a check. Another modification will give the ability to process events with as many as eight measured kinks per track.

The IBM 704 versions of the CLOUDY programs have been combined into a single program of approximately 12,000 words which is now running on the IBM 709. This program has been extended to 20,000 words with the addition of a more flexible logical control and new derived-quantities subroutines. These subroutines perform the following functions: (a) editing the beam momentum by computing the point at which the track enters the chamber, (b) computing the mass of the neutral particle, (c) computing three-body and n-body Q values, and (d) computing the Adair angle for certain types of events.

In the past 6 months approximately 8,000 events have been processed through the new CLOUDY system and approximately 2,000 events have been processed through the old system.

The FAIR system programs, which are the output-producing programs for the FOG-CLOUDY-FAIR system, are nearing completion. The current FAIR program produces detailed page listings for each event. It is clear that, as the number of events processed increases, it will become impossible for the physicist to examine all the output.

The FAIR programs being completed give detailed page listings for representative events. From this list of events the physicist can specify selection criteria for events and parameters he wishes summarized. The type of output can also be specified, i.e., the programs can produce page listings, scatter diagrams, or histograms.

The FCF (FOG-CLOUDY-FAIR) Monitor, which controls all program operation, is now running satisfactorily on the IBM 709. Many changes have been incorporated, including a new tape-handling program which provides for more efficient handling of the tape libraries and facilitates data flow between the tapes, data buffers, and the user program.

The University of Wisconsin Physics Department started using the FOG-CLOUDY-FAIR system of programs for processing events on their IBM 704 in February of this year and are now successfully processing events.

Documentation of the FOG-CLOUDY-FAIR system of programs is being written and is in the form of a reference manual, UCID Number 1340. The documentation includes the following:

1. A general description of the FOG-CLOUDY-FAIR System.

2. A detailed system description of tape and card formats, the FCF Monitor programs, and complete operating instructions for both IBM 704 and IBM 709 processing.

3. Detailed descriptions of individual programs. This section includes a program description, flow charts, chamber and assignment-request parameters, input required, and output required.

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William B. Fowler, Robert W. Birge, Philippe Eberhard, Robert Ely, Myron L. Good, Wilson M. Powell, and Harold K. Ticho, Ξ^- Production by K^- Mesons, Phys. Rev. Letters 6, 134 (1961).

Howard S. White, Data Processing for Bubble Chambers, UCRL-9475, Nov. 1960 (invited paper given at Chicago Meeting of the Institute for Computer Research, April 1960).

R.P. Ely, S.Y. Fung, G. Gidal, Y.L. Pan, W.M. Powell, and H. White, Production of the Λ_π Resonance by 1.15-Bev/c K^- Mesons, Bull. Am. Phys. Soc. 6, 291 (1961).

Robert H. Good, Regeneration of θ_1 Mesons in a 30-inch Propane Bubble Chamber (Thesis) UCRL-9606, March 1961.

T.F. Hoang, Analysis of K-Meson Production by $\bar{p}$ Annihilation, Phys. Rev. 121, 1523 (1961).

PHYSICS RESEARCH

Emilio Segrè in charge

Material for this section had not been received at the time of publication.

ACCELERATOR OPERATION AND DEVEOPMENT

BEVATRON

Edward J. Lofgren in charge

The report for August through October, 1960, has been issued as "Bevatron Operation and Development. XXVII," UCRL-9546, March 1961; for November 1960 through January 1961 as XXVIII, UCRL-9671, May 1961; and for February through April as XXIX, UCRL-9721, June 1961.

184-INCH CYCLOTRON

R. L. Thornton in charge

Reported by James T. Vale

Material for this section had not been received at the time of publication.

60-INCH CYCLOTRON

W.B. Jones in charge

OPERATION

Cyclotron Beam-Phase Measurements

An apparently suitable device for obtaining phase measurements of particles while they are being accelerated in a cyclotron has been developed and tested in the 60-inch cyclotron. The device measures beam-target current pulses directly and displays them on the cathode-ray tube of a high-speed sampling oscilloscope. Relative beam-phase observations were made between the 4-inch and 25-inch radii with the probe, and "beam" pulses were observed with widths of 1 to 1.5 nanosecond at one-half height.

Several alternative methods for obtaining internal beam signals for phase comparison were considered. They were:

(a) use of induction electrodes to monitor beam currents;

(b) use of a fast scintillator to monitor beam particles scattered from a target;

(c) direct target-current measurement of beam pulses;

(d) use of a solid-state alpha-particle detector to monitor particles scattered from a target.

Considerations of rf field interference and frequency-response requirements of the system indicated that alternative (b) or (c) is best. The use of the scintillator appeared at first the most suitable solution because of its relative freedom from cyclotron rf interference. Tests were carried out on the 60-inch cyclotron external and internal beams with such a device, but the method was later superseded by a direct beam target-current measurement. The latter method gives better time resolution and permits beam-phase measurements at smaller radii.

The direct beam probe was designed to electrically resemble a 125-Ω transmission line. See Fig. 4. The beam reaches the tip of the center conductor (target) through a slit in the hemispherical shield.

The probe was used to detect the internal beam pulses in the 60-inch cyclotron at radii greater than 19.5 in. Because of the limited dee-to-dee clearance, the 3-in. outside diameter of the probe housing prevented its use at smaller radii. The sensitivity of the probe was approximately 2.5 mv/μa average beam current. The rf interference from the dees was on the order of 0.5 volt peak-to-peak with the probe at the 30-inch radius, and approximately 3 volts at the 19.5-in. radius (approximately 140 kv dee-to-dee voltage). The spacing from dee to probe shield is 1.25 in. at the 19.5-in. radius.

Tests were made to determine the worst condition for rf pickup. The probe was positioned facing one of the dees with the probe shaft axis oriented

at nearly 90 deg to the dee surface; thus, the probe was unshielded with respect to the dee voltage. With the dee-to-ground voltage of 60 kv and the probe head 2.25 in. from the dee, the rf pickup on the probe target was 20 volts peak-to-peak.

The second direct target beam probe was designed more specifically for small-radius internal beam-phase measurements in the 60-inch cyclotron.

The probe shaft was brought in below the level of the dees to minimize its effect on the dee-to-dee capacity and consequent loading of the rf system. A sectional view of the device is shown in Fig. 5. A 125-Ω cable (RG-63) receives the signals from the beam target as shown. It is terminated at the target by two 1-watt resistors in parallel.

The rf signal from the small antenna is fed through a 50-Ω(RG-58/A) cable to an external phase-shifting and attenuating network for null balance of the rf signal picked up on the beam target probe.

Previous response tests made with a mercury relay pulser indicated that the rise time of the system composed of the probe, 100 feet of RG-63 cable, and the Hewlett-Packard sampling oscilloscope was 1 nsec. It is apparent that beam-phase variations of as little as 5 rf degrees (at 12 cm rf frequency) can be resolved quite readily with the apparatus.

The rf interference pickup on the beam target electrode was approximately 1/5 of that observed with the scintillating probe under the same conditions. The reduction is attributed to the smaller window area for beam entrance to the target tip, and the added internal shield plate, which reduces further the area for rf field penetration into the probe head enclosure. Addition of the shield plate raised the capacity between the target electrode and its surrounding shield to 2.5 μμf. The capacity without the shield was 1.7 μμf.

The probe was remotely controlled and its radial position was monitored in the cyclotron control room by observing an attached scale and pointer on a closed-circuit television.

By balancing out the interference signal (see Fig. 6), beam pulses of less than 10 mv amplitude have been observed in the presence of rf interference signals of 5 volts peak-to-peak. Careful balancing reduces a 5-volt rf signal to less than 5 mv, permitting the use of more sensitive vertical amplitude ranges on the oscilloscope. A signal of 20 to 30 mv of what seems to be the sixth harmonic of the rf frequency appears under such balanced conditions. Tests indicated that the rf-balancing technique had no observable effect on the wave form of the beam pulse signals. However, no direct beam-phase information can be obtained by reference to partially balanced out rf from the target probe, because the phase of the observed rf difference signal may vary by as much as 180 deg owing to addition of the out-of-phase components.

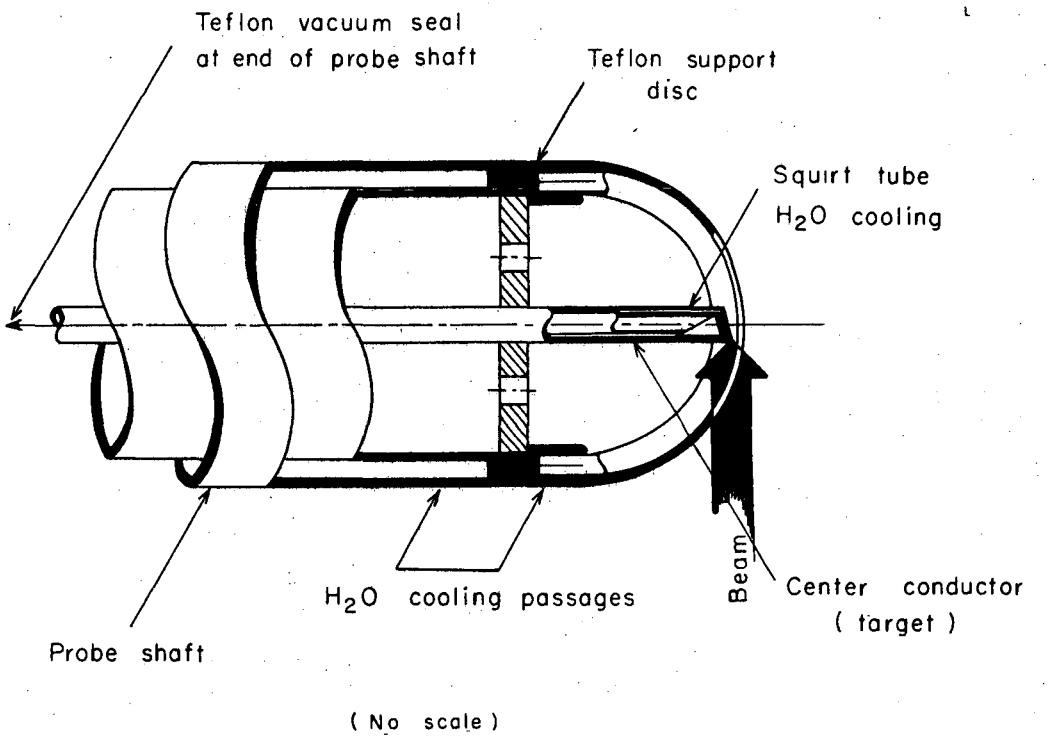


Fig. 4. Direct beam probe.

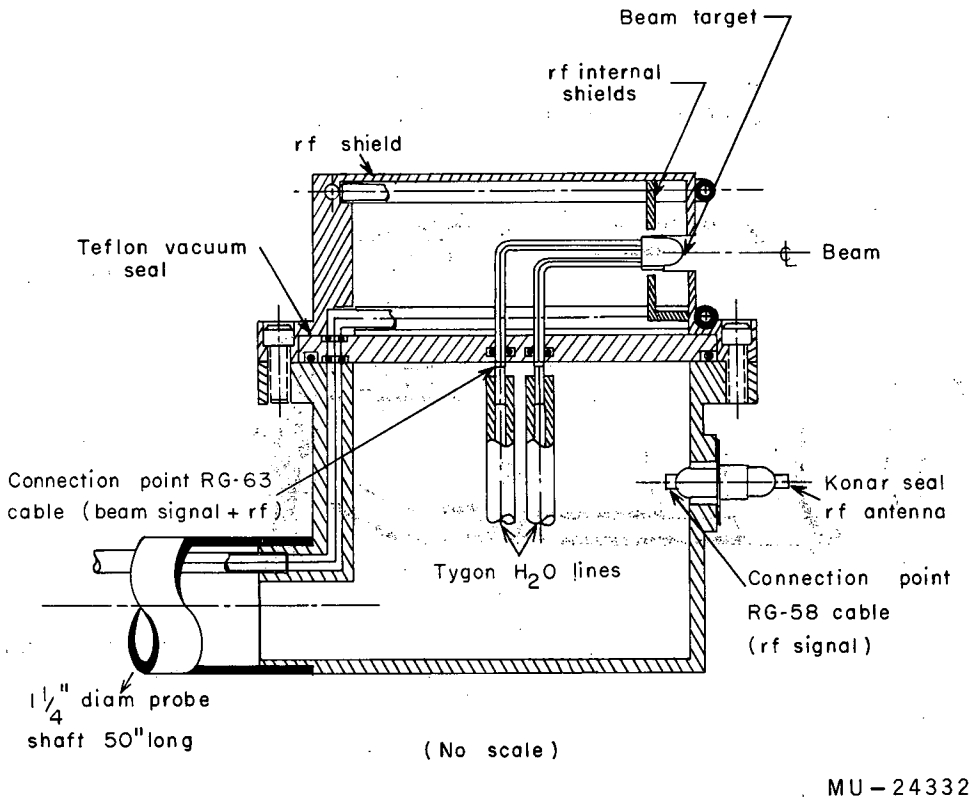


Fig. 5. Direct target beam probe for small-radius internal beam-phase measurements.

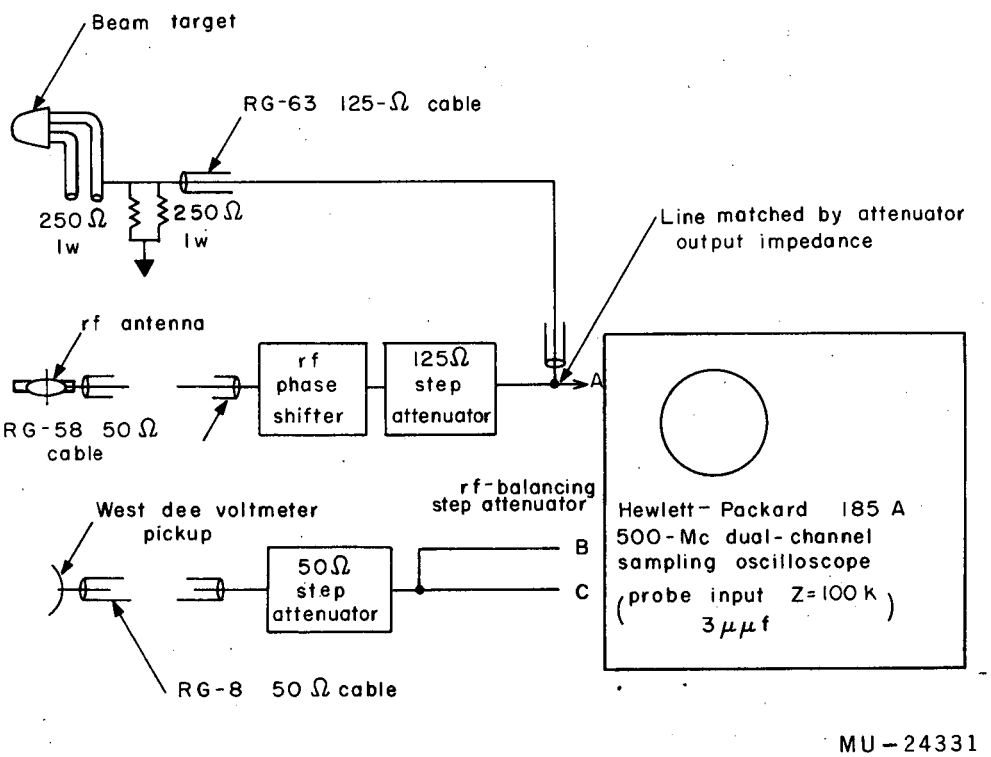


Fig. 6. Arrangement of probe.

A. Channel A probe input beam signal
B. Channel B probe input rf (for phase reference)
C. Oscilloscope trigger input

Figures 7 through 11 show the beam pulses at selected radii. The lower curve represents the pickup from the dee voltmeter, which was used in parallel to the pulse that triggers the scope. This provides a reference point for the upper curves. The upper curve shows the beam phase shift with the increasing radii. The horizontal scale is 10 nsec/cm and the vertical scale is 50 mv/cm. The cyclotron oscillator was operating at 81 kilowatts with a frequency of 11.96 Mc. It can be noted that the pulse is delayed about 2 to 3 nsec per in. of radius increase. This corresponds to approx 13 deg of rf phase per in. This can be attributed to the rate of decrease in the magnetic field.

Figures 12, 13, and 14 show the beam pulse at the 20-in. radius. Figure 14 shows quite clearly that the beam width is on the order of 3 nsec.

Figure 15 shows the beam pulse at the 5.5-in. radius superimposed on the rf without the rf being balanced out. This shows that the balancing out of the rf does not affect the raw beam shape. The scale readings are 10 nsec/cm and 200 mv/cm.

Figure 16 shows the beam pulse of the deflected beam with no rf balancing. The scale readings are 10 nsec/cm and 20 mv/cm. Note that the external beam has approximately the same spread as the internal beam.

This development work was the joint effort of Harvey Thibeau and the 60-inch cyclotron group.

Summary of Usage

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

Alpha bombardments	1,815.5 hr
Proton bombardments	473.1 hr
Deuteron bombardments	475.6 hr
Experimental bombardments	206.2 hr
Operational total	2,970.4 hr
Outage	310.0 hr
Target chamber installation	160.0 hr
Available time	3,440.4 hr
Shutdown	663.6 hr
Holidays	240.0 hr
	4,344.0 hr

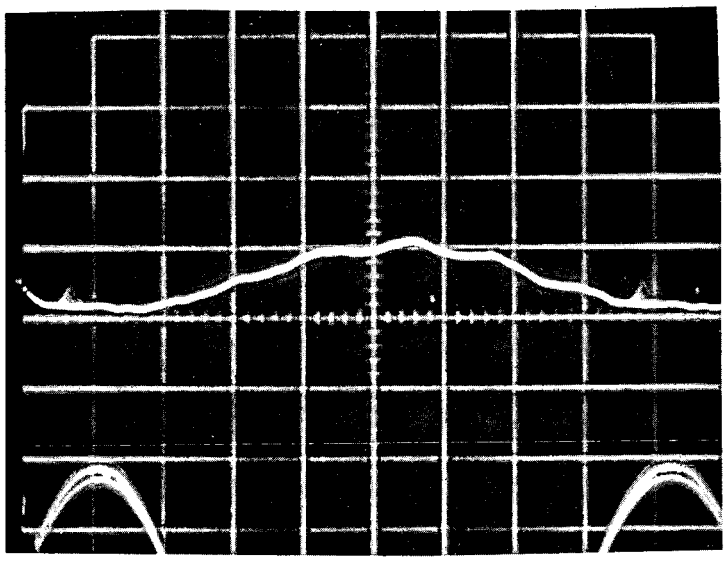
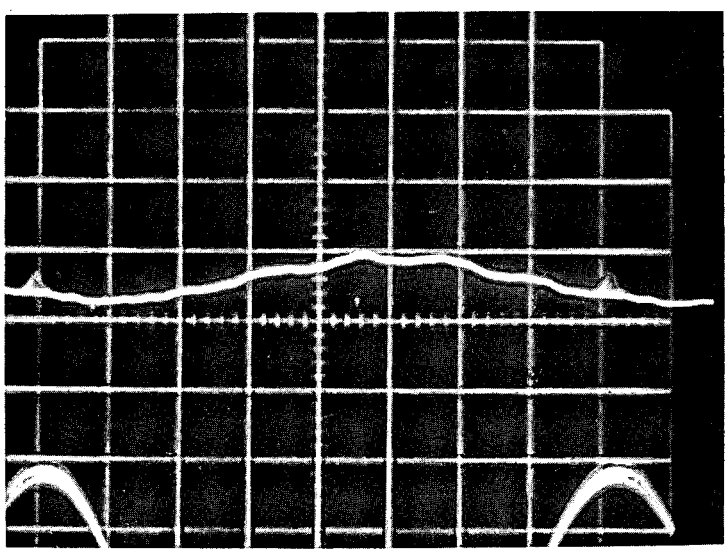
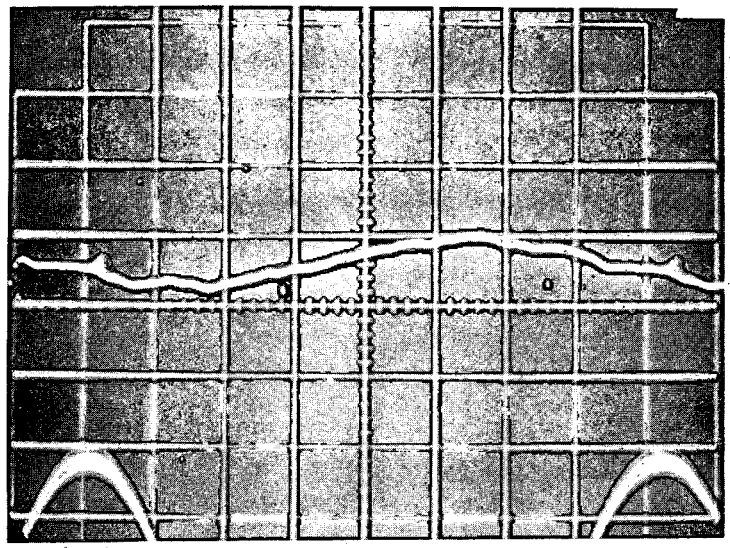


Fig. 7. Beam pulse at 20.25 in. radius.



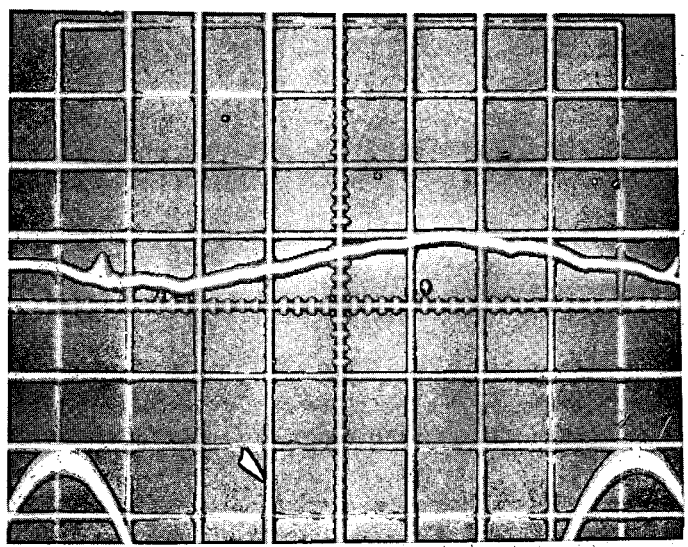
ZN-2843

Fig. 8. Beam pulse at 21 in. radius.



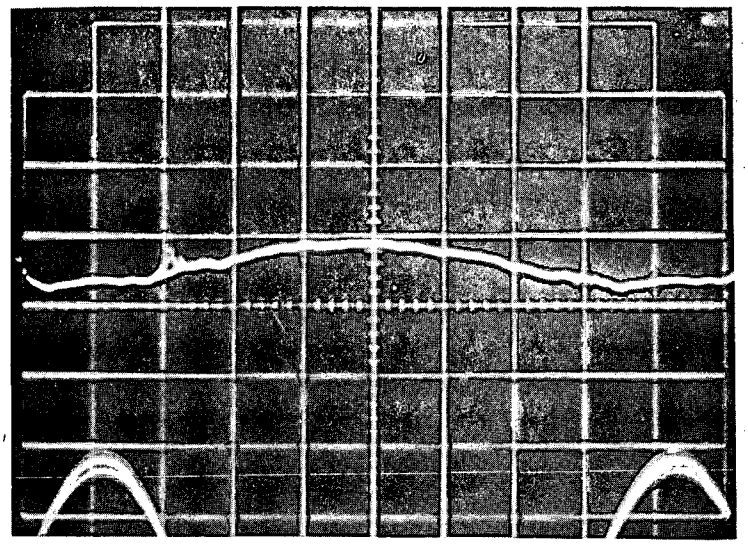
ZN-2842

Fig. 9. Beam pulse at 22 in. radius.



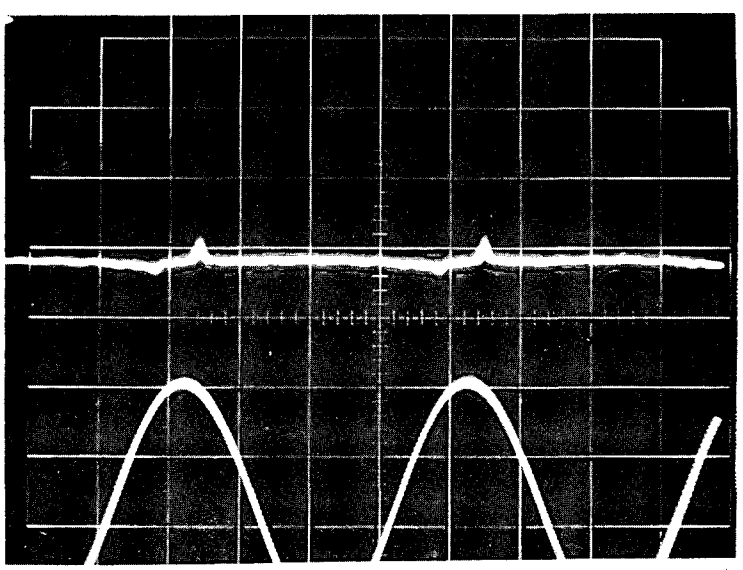
ZN-2835

Fig. 10. Beam pulse at 23 in. radius.



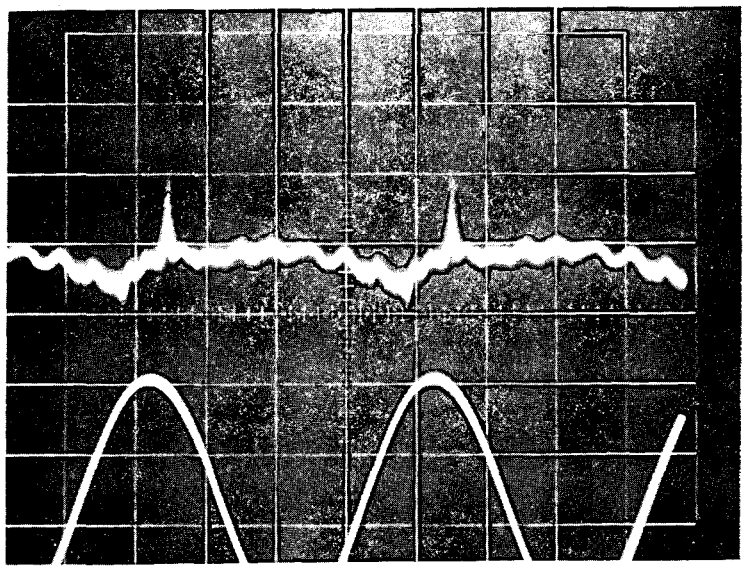
ZN-2839

Fig. 11. Beam pulse at 24 in. radius.



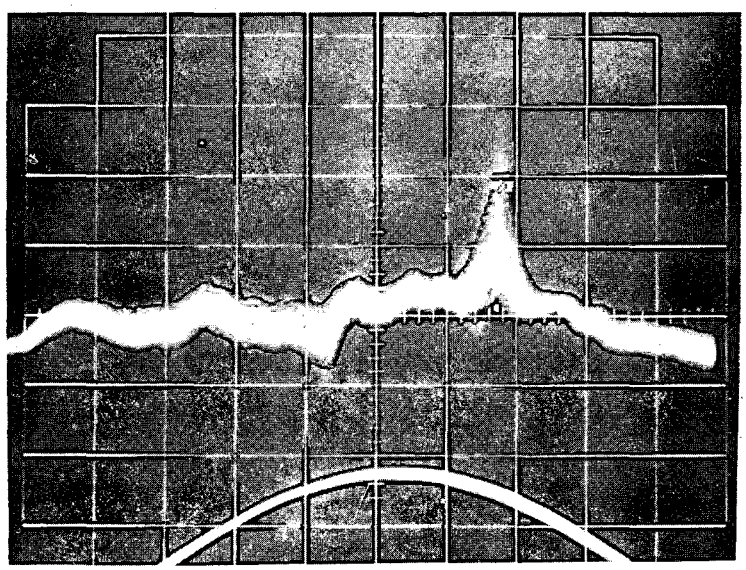
ZN-2838

Fig. 12. Beam pulse at 20 in. radius; 20 nsec/cm and 200 mv/cm.



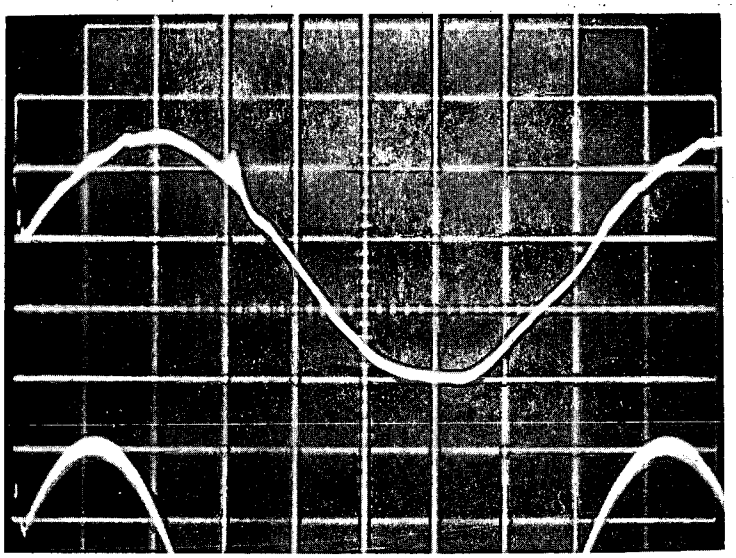
ZN-2836

Fig. 13. Beam pulse at 20 in. radius; 20 nsec/cm and 30 mv/cm



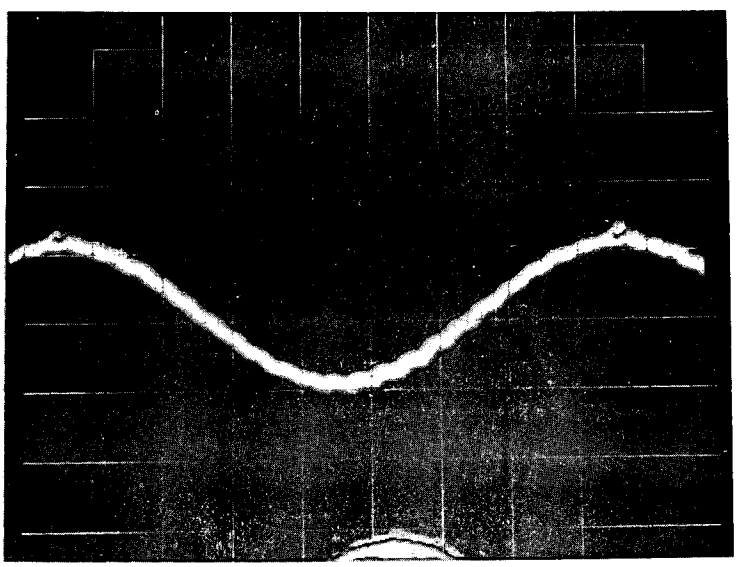
ZN-2837

Fig. 14. Beam pulse at 20 in. radius; 5 nsec/cm and 20 mv/cm.



ZN-2840

Fig. 15. Beam pulse at 5.5 in. radius superimposed on rf (rf not balanced out); 10 nsec/cm and 200 mv/cm.



ZN-2841

Fig. 16. Pulse of deflected beam with no rf balancing; 10 nsec/cm and 20 mv/cm.

An operating efficiency of 90.5% was maintained throughout this 6-month period.

During this period, the bombardment time totaled 2,970.4 hours. The Radiation Laboratory accounted for 95.3% of this time; the Chemistry group (Berkeley) used 53.5%; the Physics group used 33.4%; the Livermore Chemistry group used 6.7%; and the Biological groups used 1.7%. Of the non-Radiation Laboratory users, the U.S. Naval Radiological Defense Laboratory accounted for 3.4% , and others used 1.3%.

HEAVY-ION LINEAR ACCELERATOR

Chester M. Van Atta in charge

Reported by Edward L. Hubbard

Material for this section had not been received at the time of publication.

Information Division
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