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PHYSICS DIVISION SEMIANNUAL REPORT
November 1959 through April 1960

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GENERAL PHYSICS RESEARCH

PHYSICS RESEARCH

Luis W. Alvarez in charge

LIQUID HYDROGEN BUBBLE CHAMBERS

Operation and Development

James Donald Gow

72-Inch Chamber

Engineering data taken at the end of the antiproton experiment indicated the need for improvements in the chamber expansion system. The data indicated a higher impedance to flow in the Grove valve than would be expected under steady-state conditions (apparently due to oscillations of the rubber boot), and mixing of cold and warm gas in the expansion line due to turbulence in the gas. A test run demonstrated the value of a collimator in the expansion line consisting of some 20 parallel thin-wall tubes. This effectively increases the length-to-diameter ratio of the line while maintaining a low flow impedance.

During the preparation for the associated production run, originally scheduled in February but delayed to late April by other experiments, the following modification and system-completion work was accomplished:

1. Development and installation of a new expansion valve. This valve design, using a noncircular core, eliminates most tension in the rubber in the open position.

2. Installation of the deuterium storage, transfer, and recovery system, including the necessary heat exchangers, to permit chamber operation with D_2.

3. Installation of dual absorption purifiers to permit regeneration in operation.

4. Installation and testing of a second Worthington compressor, permitting compressor repair without interruption of refrigeration.

5. Installation in the expansion line of a permanent expansion-line collimator and a liquid-hydrogen-temperature heat exchanger.

6. Installation of a new camera control and data panel, providing binary coded decimal information on the film.

At the end of the report period, the chamber was ready for operation on the scheduled experiment.

15-Inch Chamber

The 15-inch chamber operated from November through January on an experiment involving K^+ interactions. The refrigerator was an outstanding success, permitting 24-hour-per-day operation at the Bevatron pulse rate. The convenience of this system allowed a reduction in crew to two operators per shift. The saving on hydrogen cost paid for the refrigerator installation during the first half of the run. More than 200,000 pictures were taken during the operation, using both hydrogen and deuterium in the chamber. The run was made as a service to other research groups.

The chamber is now being prepared for a K^- run scheduled for this summer.

25-Inch Chamber

A decision was made to construct a new chamber as a replacement for the 15-inch instrument. This chamber will incorporate the latest techniques, and eliminate some undesirable features of the 15-inch chamber which were required in making it serve as a model for 72-inch operation. Preliminary studies are in progress.

Development

Work is progressing on an ultraviolet absorption system for continuously measuring impurities in hydrogen at the parts-per-million level.

Optics and Data Reduction

Hugh Bradner and James Donald Gow

The completion of the first research run of the 72-inch chamber brought pressure on the entire data-analysis area. Substantial increase in effort resulted. The first of the Franckenstein measuring projectors (MP IIA) designed for 72-inch film was completed. This required a redesigned film-transport system, improvements in illumination, finishing of the x-ray servo tracking equipment, and installation of a rapid-advance frame-number indicator and an automatic film-index system. A second measuring projector (MP IIB) was 90% completed at the end of this semiannual period, and work has been started on two more.

A tape-to-tape converter, which reads the paper tape output of the measuring projector and writes magnetic tape in proper computer form, has been completed and debugged.

Six scanning tables were put into full operation, equipped with mechanical frame-finding counters. Four more were in production.

The maintenance group required for successful use of the scanning and measuring equipment was established. This has permitted a preventive maintenance program to be carried out with minimum operational down time.

The spiral reader (McCormick Reaper) program has been reoriented into a three-step approach to a full-scale system. The first phase, which involved manual operation to demonstrate feasibility of the principle, was nearly complete at the end of the report period. A Franckenstein was used to provide artificial Reaper output, which was then used as input to an IBM 704 filter program. This program is designed to take information digitized as to angle and radius, for all tracks swept by the reading spiral, and to reject all data except those connected with an event vertex. Events have been successfully run through this program.

The immediate task for the McCormick Reaper is the provision of a library of typical event readouts to permit further development of the filter program. Phase II, which envisions the production of a rapid but manually controlled prototype device for data analysis, is under study.

Some preliminary work is in progress on aids to high-speed scanning via pattern-recognition techniques.

At the end of the report period, the Franckenstein approach was working as a reasonably smooth integrated system for data from both the 72-inch and 15-inch chambers. During this period some 8000 15-inch events and 1700 72-inch events have been processed through the entire system, including the PANG and KICK programs.

Alvarez

Experimental Analysis: Interactions of K^- with Hydrogen; Development of IBM 704 Data-Reduction Programs

Arthur H. Rosenfeld

These two areas of work are linked because they have been performed mainly by the same physicists. (The K^-+p experiment from 0 to 400 Mev/c was the first in which the group set out to process 10,000 events. PANG and KICK, which stands for K-Interaction Coplanarization and Kinematics, were originally used for this experiment). All events have now been measured; they were last summarized at the Kiev Conference, in the summer of 1959. In order to complete the computer analysis, effort in the last half year has been concentrated on additional IBM programs or subroutines which do bookkeeping, calculate the path length and number of events within a "fiducial volume" of the bubble chamber, or classify KICK output. In addition, work has gone into a maximum-likelihood program which uses as input KICK fits of the individual events, and calculates phenomenological parameters for an experiment. PANG and KICK have both been extensively modified to make them more precise and at the same time more general, so that they can be used by other physicists at Berkeley as well as other American and European physicists. A number of physicists from other laboratories have visited Berkeley to study our programs and obtain copies for their own use.

Analysis programs have been developed under the direction of Arthur H. Rosenfeld, Frank T. Solmitz, and James Snyder.

Results of Experiments

Janice Button

During the last six months, the major efforts of the physicists using hydrogen bubble chambers have been directed toward further analysis of earlier experiments and improvement of computer programs. Considerable planning has been done on the 72-inch chamber associated-production experiment (π^- and π^+ on hydrogen and deuterium, from 850 to 1600 Mev/c), which has just been started. Initial design work has been completed for a forthcoming 15-inch hydrogen-chamber experiment to investigate K^- and $\bar{p}$ interactions from 0 to 700 Mev/c.

The associated-production experiment is being conducted by Frank Crawford, Margaret Alston, Philip Burke, and Norbert Schmitz. The K^--p experiment is being planned by Joseph Murray, Donald Miller, Arthur Rosenfeld, and Frank Solmitz.

Further results of experimental analysis of K^-+d interactions, from rest to 300 Mev/c; $\bar{p}$+p interactions, at 1.61 and 2.00 Bev/c; and of K^-+p interactions, at 1.15 Bev/c, are reported below. Description is given of a recent significant development in velocity-spectrometer techniques.

A study of the momentum spectrum of 145 Λ's produced by absorption of Σ^-'s in deuterium via

Alvarez

$$\Sigma^- + d \rightarrow \Sigma^0 + n + n \qquad (1)$$

$$\text{or } \Lambda + n + n \qquad (2)$$

has indicated that: (a) the ratio of the rates for (1) and (2) is 0.04±.02, in good agreement with the predictions of the impulse model;[1] (b) $M_{\Sigma^-} - M_{\Sigma^0} >$ 3.53 Mev; (c) if the Σ^- is assumed to be captured from the S-atomic orbital of the Σ^--d system,[2] the Λ-n interaction in the ^3S state is much too weak to account for the binding on the Λ in known light hypernuclei.

The analysis of nonabsorptive K^--d scattering is being extended to additional recently acquired data in the momentum interval 100 to 300 Mev/c. It has been pointed out[3] that a measurement of the scattering cross section should provide a means for deciding between the (a^+) and the (b^+) solutions of Dalitz and Tuan for the zero-energy scattering lengths of the K-nucleon system.[4]

An effort is being made to determine the frequency of nonmesic absorption in deuterium, i.e.,

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

$$K^- + d \rightarrow \Sigma^0 + n,$$

$$K^- + d \rightarrow \Lambda + n.$$

Knowledge of the in-flight cross sections will allow an estimate of the production rate for capture of K^-'s from S or P atomic orbitals of the K^--d system. It is hoped that, by comparing this rate with the mesic absorption rate at rest, a check may be made on the recent prediction that K^-'s stopped in liquid H_2 or D_2 are captured predominantly from S-atomic orbitals.[2]

The K^-+ d experiment has been conducted by Donald Miller and Joseph Murray.

Analysis has continued of results from last fall's antiproton experiment, the first run with the 72-inch hydrogen bubble chamber. As previously reported, ten examples of the reaction $\bar{p} + p \rightarrow \bar{\Lambda} + \Lambda$ were found at 1.61 Bev/c and one example of either $\bar{p} + p \rightarrow \Lambda + \Sigma^0$ or $p + p \rightarrow \bar{\Lambda} + \Sigma^0$ at the higher momentum of 2.0 Bev/c.[5] Two $\bar{\Lambda}\Lambda$ events, one with a $\bar{\Lambda}$ scatter, were seen at the higher momentum.

---

[1] Day, Snow, and Sucher, Phys. Rev. Letters 2, 468 (1959).

[2] Day, Snow, and Sucher, Phys. Rev. Letters 3, 61 (1959).

[3] Day, Snow, and Sucher, K^--d Scattering and the K^--Nucleon Scattering Lengths (submitted to Phys. Rev. Letters).

[4] Dalitz and Tuan, The Phenomenological Representation of K-Nucleon Scattering and Reaction Amplitude (submitted to Annals of Physics).

[5] Button, Eberhard, Kalbfleisch, Lannutti, Lynch, Maglić, and Stevenson, Evidence for the Reaction $\bar{p} + p$ (submitted to Phys. Rev. Letters).

A maximum-likelihood calculation yielded for the $\bar{\Lambda}$ lifetime a value of $2.95 \begin{smallmatrix} + 1.65 \\ - 0.73 \end{smallmatrix} \times 10^{-10}$ sec. Beam composition were determined by δ-ray count and also by 6-prong-annihilation count to be $1.0\ \bar{p} : 0.34\ \pi^- : 2.9\ \mu^-$ at 1.61 Bev/c and $1.0\ \bar{p} : 1.5\ \pi^- : 1.9\ \mu^-$ at 200 Bev/c.

All zero-prong events with associated double vees have been measured with the Franckenstein measuring projector; these numbered about 40 at the lower momentum and 90 at the higher momentum. With the use of the IBM kinematics program KICK, the vee decays and also the production vertices were fitted under all possible hypotheses. All the 170 single-vee, zero-prong events have been measured and are being fitted by KICK. A special program of KICK has been developed to fit two vertices simultaneously for analysis of events yielding sigma hyperons.

About 300 two-prong and 100 four-prong events have been measured and are being processed by the KICK kinematics program to study any two-pion or three-pion resonance effects. No positive results have been obtained yet.

Two-prong events of a special type have been examined in a search for the reactions

$$\bar{p} + p \rightarrow \pi^+ + \pi^-$$

$$\bar{p} + p \rightarrow K^+ + K^-$$

among approximately 10,000 annihilations of the 1.61-Bev/c antiprotons. No examples of these reactions have been reported previously, and the combined frequency of the reactions has been estimated to be less than one in 10^3 annihilations.

All the approximately 13,000 two-prong events (including about 2,000 π^- interactions and 6,000 elastic antiproton scatterings) have been examined on the scanning table, and all but 140 of these were eliminated as candidates for the reactions above. In the past month these 140 events were measured on the Franckenstein measuring projector. A preliminary analysis has selected 40 as possible two-meson annihilations. Of these, there seem to be fifteen that are good fits to $\pi^+ \pi^-$ and five that which are good fits to $K^+ K^-$. These numbers are still only tentative, as a careful analysis of the measured events has yet to be made and the probability that an annihilation with a low-energy π^0 could appear to be a two-body annihilation must be calculated. However, the numbers are probably accurate to within a factor of two.

The fractions of annihilations of 1.05-, 1.61-, and 2.00-Bev/c antiprotons that result in 6-prong events indicate that the volume Ω of the statistical theory of annihilations should be between four and six.[6]

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[6] Bipin Desai, Pion Multiplicity in Nucleon-Antinucleon Annihilation (to be published).

For 1.61-Bev/c antiprotons, the theory predicts frequencies for the two-pion annihilations of 32 in 10^4 for $\Omega = 4$ and 8 in 10^4 for $\Omega = 6$.

All annihilations yielding observable K-meson decays are being measured. No two-body K^0-$\bar{K}^0$ annihilation has been found. It can be estimated on the basis of charged and neutral K's detectable by scanning-table measurements that approximately 10% of the annihilations at 1.61-Bev/c and also at 2.00-Bev/c yield K mesons.

Analysis is being done to determine the inelastic cross section for pion production (as distinct from that for annihilation) by antiprotons. Although an upper limit of 10 mb at 950 Mev has been established by counter experiment,[7] it is expected that a better estimate can be made by fitting two-prong events. The type chosen for analysis is the two-prong with an associated 4-prong or 6-prong secondary event. Of some 400 such events, about 40 appear to be inelastic. Five of these have been fitted by KICK. The present estimate of the inelastic cross section is about 5 mb, to within a factor of two.

A further project concerns the study of antiproton polarization. Some 350 double two-prongs have been measured and are being fitted by KICK. These will be treated through maximum-likelihood calculation to determine the polarization in scattering antiprotons from protons at 950 Bev, and perhaps also the sign of the antiproton magnetic moment.

Study of effects due to turbulence and to optical or magnetic-field distortions in the 72-inch chamber is in progress. Comparison of beam-momentum determinations from fits of $\bar{p} + p \rightarrow \bar{\Lambda} + \Lambda$ with the measured values of incident momenta in the 1.6-Bev/c experiment indicates that the spurious radius of curvature is 120±40 meters. Systematic error is thus of the order of 2.5%, which is comparable to the error from multiple Coulomb scattering.

The analysis of antiproton interactions has been directed by M. Lynn Stevenson, Janice Button, Joseph Lannutti, Gerald Lynch, and Bogdan Maglić.

The analysis of K^--p interactions at 1.15-Bev/c is proceeding with the new KICK and PANG programs. KICK event types have been written and checked for all observed types of interactions. The amount of pion contamination in the beam has been determined by observing energetic δ rays.

A study of measurement and optical-distortion errors in the processing of these 15-inch chamber K^--p events is being made. In conjunction with this, investigation is in progress of the turbulence that existed in the chamber during the run, in order to eliminate systematic effects in the analysis. It is hoped that this error analysis will be completed within a month, at which time processing of the main body of the data will begin.

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[7] Elioff, Agnew, Chamberlain, Steiner, Wiegand, and Ypsilantis, $\bar{p}$ - p Cross Sections from 534 to 1068 Mev, Phys. Rev. Letters 3, 285 (1959).

The study of K^--p interactions at high momentum has been carried out by Margaret Alston and several graduate students.

It has been discovered that in vacuum-insulated high-voltage systems such as electromagnetic particle separators, the electric field, which can be held with a spark rate less than 1 per minute, is higher by a factor of two or three when the cathode is made of glass instead of metal and held at a temperature high enough so that the glass behaves as a conductor. With soda-lime glass, for example, a temperature of 100° C gives a bulk resistivity of about 10^8 ohm-centimeters and a corresponding time constant for approach to "metallic" charge distribution of about 50 microseconds in the absence of external currents. Tests have shown that the limiting field is proportional (approximately and for reasons still unknown) to the inverse square root of gap length and has a value of 200 kv/cm at a gap length of 2 cm.

Two 10-foot-long parallel-plate separators will be equipped with soft-glass cathodes for use in a new 740-Mev/c K^- beam, which is expected to be in operation sometime during the summer of 1960.

This development in separator technology has been under the direction of Joseph Murray.

Alvarez

PHYSICS RESEARCH

Walter H. Barkas in charge

STRANGE-PARTICLE RESEARCH

Walter H. Barkas, Nripenda N. Biswas, John N. Dyer, Conrad Mason, Norris Nickols, Jack Patrick, and Frances M. Smith

Charged Σ Hyperons

More than 350 decays of charged Σ hyperons have been investigated. Eighty cases of $\Sigma^{\pm} \rightarrow p+\pi^0$ at rest and 27 cases of $\Sigma^{\pm} \rightarrow n+\pi^{\pm}$ at rest yield charged secondaries whose ranges have been carefully measured to determine the Σ^+-hyperon mass. The values obtained are 1189.36±0.22 from the proton ranges and 1189.04±0.71 from the pion ranges. If the mass from the neutron mode is adopted, the π^0 mass may be calculated from $\Sigma^{\pm} \rightarrow p+\pi^0$; the value obtained is 134.5±1.3 Mev. The Σ^- mass is being estimated by the analysis of $\Sigma^- \rightarrow \pi^- + n$ decays in flight. This is not an accurate method, but should give the mass within about 2 Mev.

No case of a decay not compatible with one of the modes $\Sigma^{\pm} \rightarrow \pi^{\pm}+n$ or $\Sigma^{\pm} \rightarrow p+\pi^0$ has been found.

The decay pion has been followed in nearly all cases. From its charge, range, and the angle between the Σ and the π, we determine both charge and velocity of the decaying Σ hyperon. These data will be used to get improved estimates of the Σ^+ and Σ^- lifetimes. Previous emulsion measurements with decays in flight have been hampered by lack of direct knowledge about the charge of the Σ.

Capture of K^- Mesons by Free Protons

The reactions $K^- + p \rightarrow \Sigma^{\pm} + \pi^{\mp}$ have been subjected to detailed analysis during the period of this report.

In 16 cases of $(\Sigma^+ \pi^-)$ emission the Σ^+ comes to rest in emulsion; 3 of the π^- come to rest. These yield a Q value of 103.05±0.98 Mev. The measured momenta of the Σ^+ and π^- are, respectively, 181.24±0.27 and 181.44±1.23 Mev/c.

Similarly, 32 cases of $(\Sigma^- \pi^+)$ emission yield stopping Σ^- hyperons; 13 of the pions come to rest in emulsion. The Σ^- mass has been calculated from the Σ^+-Σ^- range difference in these events; the value obtained is 1195.67±0.33 Mev. With this Σ^- mass, the observed momentum of the Σ^- is 174.52±0.21. The momentum of the π^+, however, as deduced from its range, is 171.70±0.85 Mev/c. The Q value is measured and found to be 94.35±0.67 Mev, some 2 Mev less than that calculated from the K-meson mass. This discrepancy in energy and momentum balance has not been resolved.

The K^- mass may be calculated from either of the reactions; from $(\Sigma^+ \pi^-)$ the value is 493.7±0.3, and from $(\Sigma^- \pi^+)$ the value is 493.6±0.4 Mev. The hyperon momenta are used in this calculation.

The Λ-Hyperon Program

A study to determine the mass of the Λ hyperon and the Q value for the decay $\Lambda \rightarrow p+\pi^-$ has been completed. Of the 128 Λ-like events found in two emulsion stacks exposed to K^--meson beams, 116 were hyperons. These latter events yield a mass value of 1115.39±0.13 Mev, and the corresponding Q value is 37.55±0.13 Mev. The quoted errors include statistical errors and a 0.12-Mev error arising from systematic effects.

Currently, we are attempting to derive the Λ-hyperon production spectrum from K^--meson reactions with emulsion nuclei. This program has encountered practical difficulties which may force a reformulation of the problem. Both the spatial distribution of K^--meson interactions in the emulsion stack and the scanning efficiency for observing these interactions, parameters of the problem, have been evaluated. Presently, efforts are being directed towards finding the scanning efficiency for locating Λ-like events, another factor which enters.

Interaction Processes of K^- Mesons with Complex Nuclei

In order to obtain a detailed understanding of what occurs when a K^- meson is captured by a complex nucleus, we have pursued a long-range program of analyzing the capture stars. We have followed out 134 pions and 56 protons from one- and two-prong K^- stars at rest. Of these, 130 pions and 29 protons were of high energy. The remainder were gray or dark prongs.

Some 46 pions left the stack, disappeared in flight, or interacted before coming to rest. We are now analyzing them by a combination of the blob-counting and multiple-scattering techniques.

Analysis of the other 124 events is complete.

We shall soon finish all one-prong nonminimum events to complete the pion spectrum. We plan to analyze two-prong (π, Σ) events next.

Considerable earlier work on such stars already has been carried out by us.

Rescanning has been undertaken in order to obtain an estimate of scanning efficiency, particularly for tracks that are lightly ionizing.

μ-MESON SCATTERING

Norris Nickols and Walter H. Barkas

The scattering of 2-Bev μ mesons in iron is being studied. In cooperation with the University of Washington group, who developed the beam for

scattering studies in carbon, lead, and emulsion, we made exposures from which the multiple-scattering distribution produced by passage through 18 inches of iron is being obtained. We are particularly interested in establishing whether or not any anomalous large-angle scattering occurs. For this purpose we are comparing the observed distribution with calculations, using various nuclear form-factors.

STUDY OF π^0 PRODUCTION AND LIFETIME

Frances M. Smith and Walter H. Barkas

Some 1200 interactions of 3.5-Bev π^- mesons in Ilford K.5 emulsion have been examined for Dalitz pairs. About 10% of the stars have associated (direct) electron pairs, which are being studied. Some correspond to the decay of π^0 mesons of high energy produced in a charge-exchange process, while others arise in the multiple production of mesons by the incident pion. The energies and angular distributions of the pairs can be related to the energy and angle spectra of the π^0 mesons. We are particularly interested in those corresponding to the decay of very-high-energy π^0 mesons, because from these we are attempting to make a measurement of the π^0 lifetime. The improvements in our method over previous attempts are:

(a) a large time dilation factor,

(b) precise measurement of the coordinates of each grain center, and machine computations to avoid subjectivity,

(c) use of fine-grain emulsion.

PARTICLE-TRACK STRUCTURE

N. N. Biswas and Jack Patrick

In earlier work (Walter H. Barkas, UCRL-8687,) a theory of ionizing particle tracks was developed which has considerable generality. Extensive measurements of track blob density, lacunarity, and gap-length coefficient now have been made, and the work has been extended to studying the grain-density behavior between the minimum and plateau in emulsion. Care was taken to eliminate various interfering effects such as varying temperature during exposure.

The theory has sufficient generality to suggest that some of its features are applicable to the description of the structure of bubble tracks. Measurements on tracks in liquid hydrogen and propane are now under way.

HEAVY-ION EXPERIMENTS

William Simon, Donald Reames, and Frances M. Smith

In this report period, several experiments on charge distributions of heavy ions have been carried out. Complete data on the equilibrium

distributions for C, N, O, and Ne between 2 and 10 Mev per nucleon have been found for zapon, and some data have been obtained in gold, silver, and aluminum. Experiments with argon ions, using both equilibrium and non-equilibrium thicknesses of foils, have been made at 10 Mev per nucleon. Electron-capture and -loss cross sections are being obtained from these data.

A scattering-disintegration chamber for heavy-ion nuclear reaction experiments was built. A run was made to measure the neutron energy and angular distribution produced in the 160-Mev oxygen bombardment of gold. The plates are currently being scanned. The analysis of the neutron spectra will be made with automatic equipment and the data reduction carried out on the IBM 650 computer.

Barkas

THEORETICAL GROUP

David L. Judd

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

PHYSICS RESEARCH

Edward J. Lofgren in charge

HIGH-MOMENTUM K^- SCATTERING

V. Cook, Bruce Cork, T. F. Hoang, Leroy Kerth, Denis Keefe, William A. Wenzel, and T. F. Zipf

The total cross section of K^- scattering from hydrogen and deuterium has been measured over the range from 1.0 to 4.0 Bev/c. The results are given in Table I. Also, the upper limit of the charge-exchange cross section has been measured at several energies and the angular distribution of 2.0-Bev/c K^--p elastic scattering has been measured.

Table I

Total cross sections for K^--p and K^--n reactions. A small correction for forward scattering is included. The neutron cross section has been calculated with the help of the Glauber formula, $\sigma_D = \sigma_n + \sigma_p - (4\pi)^{-1} \sigma_n \sigma_p \frac{1}{R_D^2}$. Stated errors are statistical only.

P (Bev/c)	σ_p (mb)	σ_d (mb)	σ_n (mb)
1.0	47.1 ± .76	74.1±.67	30.9±1.3
1.125	43.5 ±1.20		
1.25	33.7 ± .62	60.1±.38	29.0± .79
1.375	31.1 ± .64		
1.5	32.4 ± .58	56.3±.47	26.2± .81
1.625	32.5 ± .58		
1.75	32.6 ± .38	54.4±.43	23.9± .62
2.0	30.7 ± .28	51.1±.65	22.2± .77
2.5	27.0 ± .38	47.2±.43	21.8± .61
3.0	25.5 ± .30	46.0±.43	22.0± .56
4.0	25.6 ± .50	44.5±.47	20.3± .75

The K^- mesons were identified with the aid of two high-pressure gas Čerenkov counters, up to 2000 psi methane. The K^- mesons were scattered from a 4-ft-long liquid hydrogen or deuterium target. The scattered particles were detected with scintillation counters, and for the angular distribution experiment a 20-in.-diameter 48-in.-long threshold Čerenkov counter, 300 psi sulphur hexafluoride, in conjunction with a deflecting magnet, was used to reject the K^- mesons that decayed in flight.

Lofgren

One of the surprising results is that the K^--p cross section remains much higher than the K^+-p cross section, even at high energy.

$\bar{p}$-p CROSS SECTIONS AT 1.0, 1.25, AND 2.0 BEV

Rafael Armenteros,* Charles A. Coombes,† Bruce Cork,
Glen R. Lambertson, and William A. Wenzel

A paper of this title has been submitted to Physical Review.

DECAY ASYMMETRY OF Σ^+ AND Λ^0 HYPERONS

Rodney L. Cool,‡ Bruce Cork, James W. Cronin,**
Leroy Kerth, and William A. Wenzel

The asymmetries in the decay of Σ^+ and Λ^0 hyperons produced by 1.0 -Bev/c pions in hydrogen were measured.

A paper of this title has been submitted to Physical Review.

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*On leave of absence from the Laboratoire de Physique, Ecole Polytechnique, Paris and CNRS, France.

†Now at Idaho State College, Pocatello, Idaho.

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**Now at Palmer Physical Laboratory, Princeton University, Princeton, New Jersey.

K^+-SCATTERING EXPERIMENT IN HYDROGEN AND DEUTERIUM

Sulamith Goldhaber*

Interactions of K^+ mesons in hydrogen and deuterium were studied as a function of incident K^+ momentum. A highly separated K^+ beam was constructed[1] for a momentum of 700 Mev/c. The lower momenta were obtained by degrading the particles with absorber placed in front of the detector. In this manner we obtained beams of 520, 360, and 220 Mev/c. In addition to the above momenta we also studied interactions at 875 Mev/c by tuning the magnets in the system to the higher momentum.

The detector used during this experiment was the Alvarez 15-inch hydrogen and deuterium bubble chamber.

The intensity and separation of the beams are summarized in Table II.

Table II

Beams used in experiment

P_K (Mev/c)	Background/K^+	No. of K^+ per 10^{11} protons
700	approx 5×10^{-3}	10
875	approx 5×10^{-2}	25

*This work was done in cooperation with Gerson Goldhaber and Hugh Bradner of this Laboratory and Donald Stork and Harold K. Ticho of UCLA.

[1] Gerson Goldhaber, Sulamith Goldhaber, John A. Kadyk, T. T. Stubbs, Donald K. Stork and Harold K. Ticho, Separated K^+ Beams, Bev-483, Feb. 1960.

In Table III a summary is given of the type of interactions that can occur in K^++H and K^++D collision, the quantities to be determined, and the number of pictures taken.

Table III

Interactions of K^+ mesons with hydrogen and deuterium

Target	Reaction		Quantity being measured	No. of pictures	Total No. of events
		$K^+ + p$	$d\sigma/d\Omega$		
		$K^+ + \pi^+ + n$			
H	$K^+ + p \rightarrow$			10^5	5×10^3
		$K^+ + \pi^0 + p$	σ_{tot}		
		$K^0 + \pi^+ + p$			
		$K^+ + d$	$d\sigma/d\Omega$		
		$K^+ + p + n$	$d\sigma/d\Omega$		
D	$K^+ + d \rightarrow$			10^5	10^4
		$K^0 + p + p$	$d\sigma/d\Omega$, $m_{K^0} - m_{K^+}$		
		pion production	σ_{tot}		

So far we have completed the scanning of the 520-Mev/c, 320-Mev/c, and half of the 220-Mev/c film taken in the deuterium run. The measurements of the events found have also been completed. Some preliminary cross sections are already known; the computations are, however, not yet complete.

Lofgren

PION-PION CORRELATIONS

Sulamith Goldhaber*

A paper attempting to explain the pion-pion correlations found in pions emitted from antiproton annihilations has been published.[1] A more detailed discussion is given by Gerson Goldhaber elsewhere in this report (p. 34.)

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*This work was done in cooperation with Gerson Goldhaber and Wonyong Lee of this Laboratory and A. Pais of the Institute of Advanced Study, Princeton, New Jersey.

[1] Gerson Goldhaber, W. P. Fowler, S. Goldhaber, T. F. Hoang, T. E. Kalogeropoulos, and W. M. Powell, Pion-Pion Correlations in Antiproton Annihilation Events, Phys. Rev. Letters 3, 181 (1959).

PHYSICS RESEARCH

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

INTERACTIONS OF μ^- MESONS

Selig N. Kaplan

Preparations are in progress for the measurement of the relative capture rate of μ^- mesons by the elements of a chemical compound, and for the measurement of the energy spectrum and asymmetry of emission of neutrons produced in μ^- capture. In connection with this work we have built and tested a scintillation counter capable of differentiating between pulses produced by neutrons (protons) and photons (electrons). (For detailed information on the principle of operation of such a counter see, for example, F. D. Brooks, Nuclear Instruments and Methods, 4, 151 (1959).)

In a preliminary cyclotron run using this counter we were thwarted by excessive background. Improvements have been made in both the counter shielding and its duty cycle, and another run is scheduled for May.

ANTINEUTRONS

John A. Poirier

A preliminary analysis of the low-momentum data (1.6 Bev/c) is now completed. These data came from a little less than one-half of the pictures taken last summer in the 72-in. liquid hydrogen bubble chamber. The bubble chamber was exposed to a separated beam of antiprotons produced in the Bevatron.

This preliminary analysis yields the following cross sections:

$$\sigma(\bar{p} + p \rightarrow \bar{n} + n) + \sigma(\bar{p} + p \rightarrow \bar{n} + n + \pi^0) = (8.5 \pm .9) \times 10^{-27} \text{cm}^2$$

and $$\sigma(\bar{n} + p \rightarrow \pi's + K's) = 45 \pm 6) \times 10^{-27} \text{ cm}^2.$$

The latter cross section contains a calculated 14% correction for one-prong annihilation; i.e., into one positively charged particle plus neutrals. This process was indistinguishable from the background of proton recoils. Angular distributions of the elastic charge-exchange process have also been obtained; corrections were made for the chamber geometry, which biases this distribution. Final analysis of these data is now under way. In particular the cross section for the inelastic charge-exchange process, i.e., $\sigma(\bar{p} + p \rightarrow \bar{n} + p + \pi^-)$, is being analyzed. From this cross section we can estimate $\sigma(\bar{p}+p \rightarrow \bar{n} + n + \pi^0)$ and obtain more detailed knowledge about the elasticity of the charge-exchange process.

Moyer-Helmholz

Further analysis of the low momentum will include π-π angular correlations in $\bar{n}p$ annihilations, and also the probability of K-meson production.

After complete analysis of the low-momentum half of the run is completed, the high-momentum data (2.0 Bev/c) will be analyzed. This section of the run is of poorer quality--fewer $\bar{p}$'s per picture and more background. However, with the experience gained with the low-momentum pictures and with the counter data that are available for the higher momenta, this analysis should be possible.

This experiment has been carried out in collaboration with the Alvarez Group.

p-n CROSS-SECTION RESEARCH AT THE BEVATRON

Thomas Devlin and Michael Longo

The results of two pion-scattering experiments completed by this group last summer have been published.[1] In these articles we have mapped out in considerable detail the variation of the total cross sections for the scattering of pions on protons with momentum in the range 0.5 to 1.8 Bev/c for negative pions (Fig. 1). In addition to confirming the existence of maxima in the total cross sections for both positive and negative pions, these experiments permitted accurate determination of energy values of these maxima, and also indicated the possibility of a new resonance in the cross section for positive pions. What seems to be the high-energy limiting value of the π^+-p total cross section has been determined quite accurately.

Data obtained in one of these experiments on the scattering of positive pions on several heavy nuclei (at 3.0 Bev/c) are currently being analyzed by comparing the experimental results with cross sections calculated by use of a potential-well model for the nucleus. A program has been prepared to calculate these cross sections with the IBM 704 computer. This program makes an essentially exact solution of the relativistic wave equation for a particle scattered by a complex potential well with a diffuse edge. At these energies the depth and size of the potential well are directly related to the distribution of matter in the nucleus.

Several measurements of the differential cross section for pions on protons are in the design and fabrication stages. One of these will measure the differential cross section in the resonance region in order to get information on the quantum numbers of the states involved in the resonances. The structure of the nucleon will be investigated by using 3-Bev pions as a probe by means of a differential-cross-section measurement at that energy.

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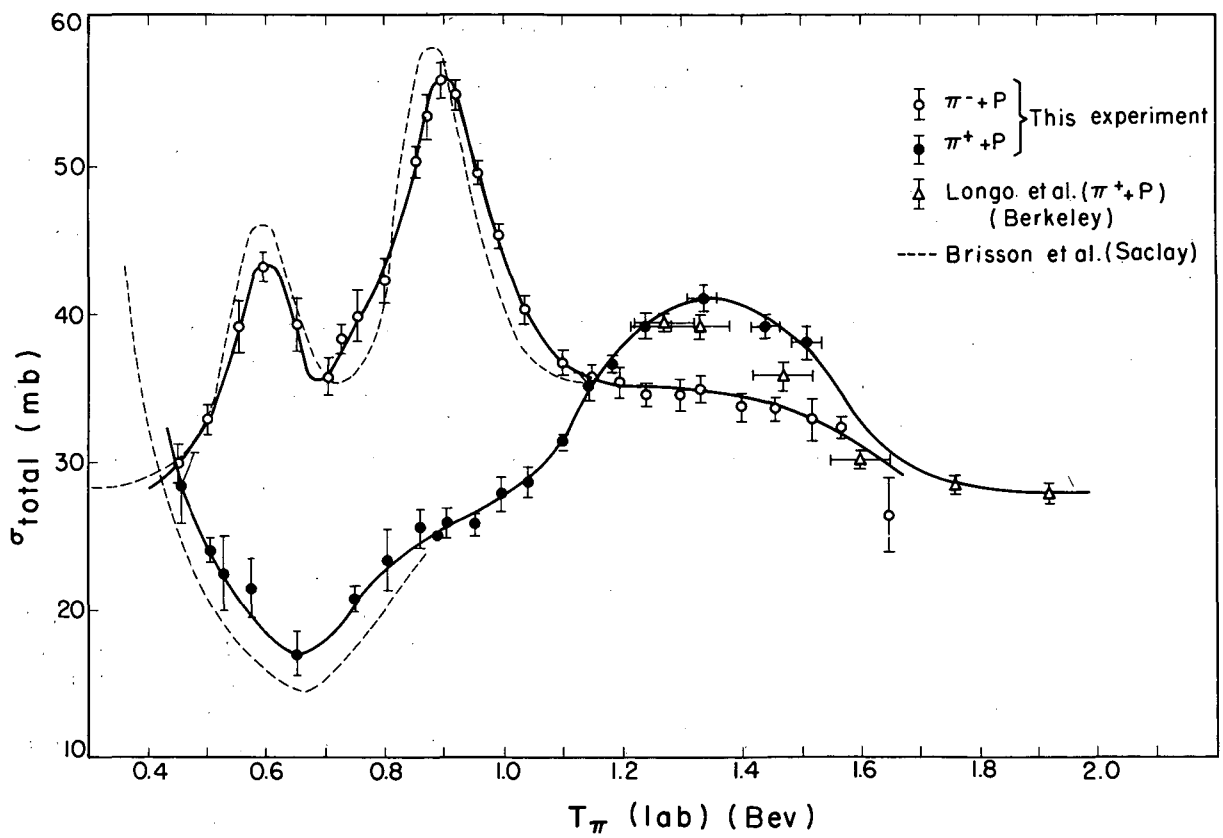
[1] Thomas J. Devlin, Barry C. Barish, Wilmot N. Hess, Victor Perez-Mendez, and Julius Solomon, Phys. Rev. Letters 4, 242 (1960); Michael J. Longo, Jerome A. Helland, Wilmot N. Hess, Burton J. Moyer, and Victor Perez-Mendez, Phys. Rev. Letters 3, 568 (1959).



MU-19237

Fig. 1. Results for total pion-proton cross sections between 0.5 and 2 Bev/c.

Several other experiments concerned with the nature of the pion-nucleon interaction are being studied for feasibility.

p-p-π^0 EXPERIMENT

Gilbert Mead and Robert Cence

The high-energy gamma-ray experiment is presently in the midst of a third cyclotron run (May 1960). This experiment measures the gamma-ray spectrum from π^0 mesons produced in p-p collisions at various angles with respect to the proton beam.

The second run, carried out at several angles between 5 and 60 deg (lab), showed that it was quite important to obtain accurate measurements on the gamma-ray energy spectrum at the low-energy end. To do this it was necessary to modify the geometry of the two pair spectrometers in use so that the corrections resulting from the vertical scattering of the electron-positron pairs by the converter were greatly reduced. These modified pair spectrometers are now being used in this third run.

The results of the second run showed that the π^0 angular distribution cannot be as nearly isotropic as earlier Russian data at 660 Mev indicated. Our data show that π^0 production at 730 Mev possesses a marked contribution proportional to at least the second power of $\cos\theta$ (θ being defined as the center-of-mass angle between the incoming proton and the π^0 meson). Eventually we expect to obtain data accurate enough to deduce the precise angular and energy distribution of the π^0 mesons.

π^- FROM DEUTERIUM

William P. Swanson

The photoproduction of π^- mesons from deuterium was observed in the 4-inch hydrogen bubble chamber, and the total cross section, the ratio of π^- to π^+ production, and the cross section for π^- production on bare neutrons have been determined. The total cross section is in agreement with the work of Adamovich et al. The ratio

$$\frac{\sigma(\gamma n, \pi^- p)}{\sigma(\gamma p, \pi^+ n)} = 1.27 \pm 0.11$$

is corrected for Coulomb interactions among all final-state particles and is derived from the charged pions from deuterium. If one accepts the recent calculations of Ball et al., which give

$$\frac{\sigma(\gamma n, \pi^- p)}{\sigma(\gamma p, \pi^+ n)} = 1.28\,(1 - 0.19\,\Lambda),$$

these data yield a small value for the new parameter Λ which arises from the photon three-pion interaction. The Chew-Low polology technique has been employed to derive the bare neutron cross section $\sigma_{\gamma+n\rightarrow\pi^-+p}$ from observations on deuterium. The s-wave constant in the $(\gamma n, \pi^- p)$ cross section $a_0^- = \frac{\sigma}{4\pi W}$ is evaluated at 153 Mev and $a_0^- = 3.26\pm0.3\times10^{-29}$ cm^2/sr, in substantial agreement (considering the inherent difficulties in the polology technique) with the dispersion-theory result of 2.7×10^{-29}.

THRESHOLD PHOTOPRODUCTION OF π^+ FROM HYDROGEN

Donald McPherson

The status of the π^+ photoproduction experiment, $\gamma+p\rightarrow\pi^++n$, is as follows. The experiment was conducted in the summer of 1959, with the 4-in. liquid hydrogen bubble chamber and the electron synchrotron. The synchrotron was limited to 200 Mev peak energy.

The bubble chamber film is presently being scanned and measured. From a total 400 usable rolls of film, nearly 3000 π^+ events have been found in 300 scanned rolls, and 150 of the rolls have been measured. The method for analyzing these events has recently been programmed on the IBM 650 computer.

ELECTRON TRIPLET PRODUCTION BY HIGH-ENERGY PHOTONS IN HYDROGEN

Duane Gates

The Alvarez 4-in. liquid hydrogen bubble chamber was used to detect electron "triplets" produced by hardened 320-Mev bremsstrahlen from the synchrotron. Approximately 17,000 useful stereo pictures were obtained. The pictures were scanned at least twice and nearly 4,000 triplets were found and measured to obtain projected electron curvatures and the projected angle of recoil. A corresponding number of nuclear pairs was also measured. All measurements were transferred to IBM cards and processed on the IBM 650 computer to obtain the incident photon energy, electron energies, and true recoil angle in space. At present an analysis of the computer results as well as the monitoring data is nearing completion. The results will include (a) the total cross section for triplet production, (b) the partition function for energy sharing, (c) the recoil momentum distribution, and (d) the recoil angular distribution.

PION PRODUCTION BY PIONS

Barry C. Barish, Richard J. Kurz, Julius Solomon, and Victor Perez-Mendez

Preparations are under way for a continuation of the inelastic π^--p cross sections at 370-and 430-Mev incident pion energies. A run is scheduled

on the cyclotron in June to measure the differential distribution in energy and angle of one of the inelastic pions, using a magnetic spectrometer.

π^--p ELASTIC AND CHARGE-EXCHANGE SCATTERING

John C. Caris, Lester K. Goodwin, Robert W. Kenney, and Victor Perez-Mendez

One run was held at the cyclotron in November 1959 in which π^- at incident energies of 230, 260, and 290 Mev energy were used. These data together with previous data at 317, 370, and 430 Mev have been analyzed in terms of partial waves and to some extent in terms of phase shifts. The partial-wave analysis of π^--p elastic scattering shows that the data require D waves at 290 Mev and above; at 427 Mev the best fit to the data requires F waves, also.

In contrast to this, the analysis of the charge-exchange differential data shows no indication of the presence of D or higher waves at the same energies. This may be due to an accidental cancellation of terms; however, this cancellation imposes an additional condition on the phase shifts involved and thus helps in selecting the more reasonable fits.

Two reports have been written on these experiments:

John C. Caris, Charge-Exchange Scattering of Negative Pions by Hydrogen at 230, 260, 290, 317, and 371 Mev (Thesis), UCRL-9048, March 1960; Lester K. Goodwin, The Elastic Scattering of Negative Pions by Protons at 230, 290, 370, and 427 Mev (Thesis), April 1960.

Moyer-Helmholz

PHYSICS RESEARCH

Wilson M. Powell and Robert W. Birge

INTERACTION STUDIES

Elastic π^+-p Scattering

Twenty thousand pictures were obtained of 750-Mev/c π^+ mesons in the 15-inch hydrogen bubble chamber, for the purpose of studying elastic scattering.

θ-$\overline{\theta}$ Mass Difference

One hundred fifty thousand pictures were obtained of 875-Mev/c K^+ mesons in propane, to determine the θ-$\overline{\theta}$ mass difference. Preliminary results based on 100 events show a mass difference near unity. The scanning for this was done by Fry in Wisconsin.

Pion-Pion Interactions

Two thousand five hundred two-prong events produced by 3.2-Bev/c π^- mesons in the 72-inch hydrogen chamber have been measured, and interpretation is proceeding. This is a continuation of earlier work based on the proposal by Chew and Low, Phys. Rev. 113, 1640 (1959).

Λ^0-p Scattering

Seventy-five cases of Λ-proton scattering have been found, and analysis proceeds.

Σ^- and Σ^+ Scattering on Protons

Fifteen cases of Σ^- and Σ^+ scattering on protons are being analyzed.

The Proton Helicity from Λ^0 Decay

Although about 250 cases have been found in which the proton from the decay of a Λ scattered on carbon, no conclusive result has been possible on the helicity of the Λ.

Capture Rate of the μ^- in Carbon

F. Russell Stannard found 185 μ^- interactions out of 2334 μ^-'s coming to rest in propane. This gave a capture rate of the μ^- in carbon of $(0.36 \pm 0.04) \times 10^5$/sec.

π^--p Elastic Scattering Near the Second Resonance

The analysis of these data is nearing completion and will give 600 events at 600 Mev, 1000 events at 650 Mev, and 1200 events at 750 Mev.

IMPROVEMENT IN CHAMBER OPTICS

The optical quality of the 30-inch propane bubble chamber pictures has been improved greatly by more careful stirring of the hydrostatic supporting oil.

DATA ANALYSIS FOR THE 30-INCH PROPANE BUBBLE CHAMBER

Program Development

FOG IV has been in routine operation during this period. The following program extensions have been added to the system: (a) adaptation for analysis of 72-in. hydrogen chamber pictures; (b) automatic display (using the Livermore CRT) of measured points from their least-squares fitted interpolation curves; (c) a program which selects measured data according to criteria given by the physicists, and supplies for the selected events mass codes and processing instructions to be used by the CLOUDY processing system; and (d) several input data-sorting and -editing routines to increase the efficiency of the data-processing system.

Some sections of the CLOUDY IV program system have been put into routine operation. Among these are the input and output library handling programs, a program that abstracts data from events selected to meet prespecified criteria, and a program that calculates quantities of physical interest derived from the measured data. Development is continuing on a program to simultaneously apply kinematic constraints to all vertices of multivertex events. The program for calculation of derived quantities is being extended to allow a wider range of events and to provide greater flexibility of output.

One program of the FAIR system has been completed. This is the page-output program which yields all desired output from the FOG-CLOUDY calculations on a single set of pages. Extensions will be made to this program system to provide selection of data to be included in output summaries and to provide for cathode-ray-tube displays of histograms, scatter diagrams, and other graphical description of data. Included with the plots will be tabulations giving cross reference to the page output so that these displays can be used for quality control and investigation of the data as well as for final summarization.

Data Processing

Summarization and tabulation of approximately 12,000 selected events of the 750-Mev/c π^- meson experiment have been completed.

The following table shows the number of origins measured and analyzed for each experiment. All data except the 3.2-Bev/c π^- experiment were obtained in the 30-in. propane bubble chamber; the 3.2-Bev/c π^- data were obtained with the 72-in. hydrogen bubble chamber.

Experiment	Events Processed (November-April)
5.2-Bev/c π^- mesons	1,399
750-Mev/c π^- mesons	4,855
1.1-Bev/c K^- mesons	1,709
700-Mev/c θ^0_2 mesons	2,722
3.2-Bev/c π^- mesons	3,035
755-Mev/c K^+ mesons	415

PAPERS ISSUED

Fowler, Good, Matsen, Birge, Hirsch, Muller, Piccioni, Powell, and White, Regeneration of K_1 Neutral Mesons from Diffraction Scattering of K_2's, UCRL-8983 Abstr., Nov. 1959.

Birge, Lanou, Whitehead, and Courant, A new Use of Counter Control in Cloud Chamber Operation, Nuclear Instr. Methods 5, 161-164 (1959).

F. Russell Stannard, The Total Absorption Rate of Muons in Carbon, UCRL-9164, April 1960.

Muller, Birge, Fowler, Good, Hirsch, Matsen, Oswald, Powell, White, and Piccioni, Regeneration and Mass Difference of Neutral K Mesons, Phys. Rev. Letters 4, 418 (1960) (BNL-4692).

Oreste Piccioni, Invited paper at Annual Meeting of Am. Phys. Soc., Diffraction Scattering of θ_1 Particles, Bull. Am. Phys. Soc., Ser. II 5, 54 (1960).

PHYSICS RESEARCH

Emilio Segrè in charge

π-π SCATTERING EXPERIMENT

Tom Ypsilantis, Clyde Wiegand, Herbert M. Steiner, Joseph Lach, Tom Elioff, William B. Johnson, and Leonard B. Auerbach

An experiment is in progress at the Bevatron to test the theories of Chew, Low, and Mandelstam concerning a resonance in the interactions of π^+ and π^- mesons. Two reactions are being studied at incident-pion momenta between 1.25 and 2 Bev/c:

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

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

in which the energy of the "spectator" neutron lies in the interval 5 to 50 Mev. According to the theory, the cross section for events involving two π^+ mesons should be dictated by the statistics of phase space, whereas the yield of events in which a π^+ and a π^- are emitted should be considerably higher. The resonance is expected to occur in the region where the total energy of the pions in their center-of-mass system is about 600 Mev. This prediction is based on an analysis (Fulco and Frazer) of the form factor in e-p scattering.

At certain of the above specified incident-pion momenta and emitted-pion energies, kinematics requires that all three particles lie within a cone of 60-deg half angle with respect to the incident beam. A dish-shaped array of scintillation counters was constructed as shown in Fig. 2. A liquid hydrogen target 4 in. thick is used at the center of the spherical array. Seven quantities are measured in the experiment: θ and ϕ for each of the two pions and the neutron, and the energy of the neutron. These measurements are accomplished by dividing the array of 84 counters into seven annular rings of constant θ extending from 4 to 60 deg. Each ring is further divided into 12 elements, making equal ϕ intervals of 30 deg. All the counters are 6 in. thick and the total weight of the scintillator material amounts to about 1400 kg. The reason for making the counters so thick is that the same counters detect neutrons as well as pions. The efficiency for counting recoil protons in the plastic (chemically CH) ranges from about 10% to 30%, depending on the neutron energy.

By recording pulses from each of the elements, we obtain the angular coordinates of the two pions and the neutron. The neutron is distinguished by its time of arrival at the dish with respect to the time of arrival of the pions. A measurement of this difference in time of flight from the hydrogen target gives the neutron energy. The difference in time of flight ranged from 11 to 43 nanosec.

A system of counters in the incident-pion beam gives a signal when a beam particle is scattered by the target. This signal is combined with appropriate signals from groups of counters in the array in order to generate a trigger. The trigger signal says "look into the array and record the pulses from those elements which have received a particle." This is done by employing

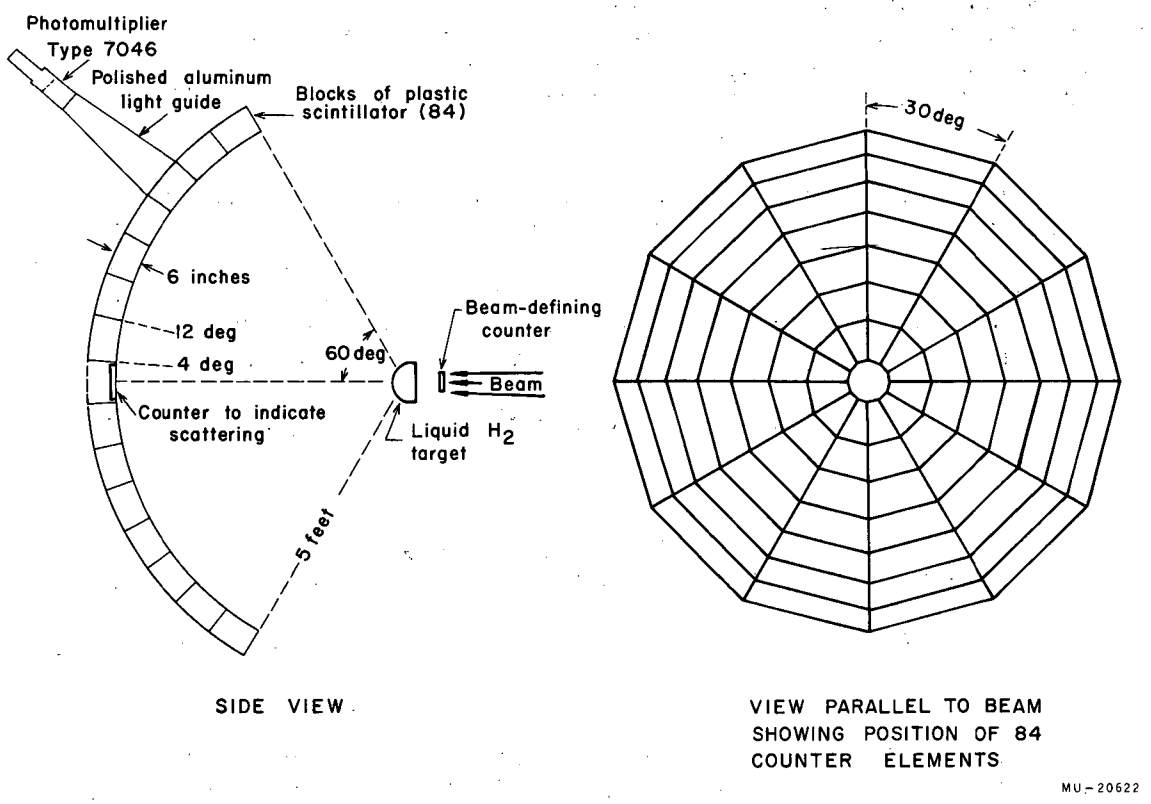


Fig. 2. Arrangement of scintillation counters.

one set of 84 twofold coincidence circuits for the pion coordinates and another set of 84 circuits for neutron coordinates. The information is temporarily stored in a magnetic-core memory and subsequently fed to a tape between Bevatron pulses. The electronic data-storage apparatus was developed by Dick Mack and his group and is described by Clyde Wiegand in the report of the CERN September 1959 Conference on High Energy Accelerators and Instrumentation. A chronotron made by Quentin Kerns and his group registered the difference in time of flight of the pions and the neutron. This information was also put on tape. The apparatus could accept and store 10 such events per Bevatron pulse.

Finally the tapes were taken to an IBM 704 computer that was programmed to sort out the events that satisfied the kinematics of interest to the experiment. The data sheets written by the computer gave, for each event, the energy of the pions in their center-of-mass system, the θ angular coordinate and energy of the neutron, and the names of the individual counters that gave the data, as well as the Bevatron pulse serial number.

As the first trial of the apparatus was concluded only recently, it is too early to announce any specific results.

PHASE-SHIFT ANALYSIS OF ELASTIC π^+-p SCATTERING EXPERIMENTS AT 310 Mev

James H. Foote, Owen Chamberlain, Ernest H. Rogers, and Herbert M. Steiner

The SPD phase-shift analysis discussed in the preceding semi-annual report and in Phys. Rev. Letters 4, 30 (1960) has been extended to include F waves. Although the values of the phase shifts in our one previously acceptable solution (Fermi type) have not changed greatly with the addition of the two F-wave phase shifts, the errors on most of the phase shifts have increased in magnitude. Also, three new well-fitting solutions have been noticed. Two of these combine the Yang and Minami ambiguities and are therefore unlikely to be valid. The third is of the Fermi type, with larger D-phase shifts than in our original Fermi set.

We are currently making a random SPDF phase-shift search in order to determine if any further well-fitting solutions exist. Comprehensive reports are being written covering both the π^+-p experimental work at 310 Mev and the phase-shift analysis.

ELASTIC π^--p SCATTERING EXPERIMENTS AT 310 Mev

Hugo R. Rugge and Olav T. Vik

Experiments are being planned to investigate π^--p elastic scattering at 310 Mev. The necessary pion beam will be set up at the 184-in. cyclotron and will be similar to that employed in the π^+-p experiments. Quantities to be

investigated are the differential cross section, the total cross section, and the polarization of the recoil protons. An initial run is scheduled for June 1960.

n-p SCATTERING CROSS SECTION

Rudolf R. Larsen and Hugh Rugge

Measurements of the neutron-proton differential cross section at 710 Mev in a center-of-mass angular region 180 to 160 deg have been completed at the 184-in. synchrocyclotron.

The neutron beam was produced by charge-exchange scattering of the 740-Mev proton beam in deuterium. The protons elastically scattered from a liquid hydrogen target by these neutrons were detected with a velocity-selecting counter telescope.

Following a suggestion by Chew,[1] the cross-section data are presently being analyzed for the value of the pion-nucleon coupling constant. (No results are available yet.)

THE INFLUENCE OF THE BOSE-EINSTEIN STATISTICS ON THE ANTIPROTON ANNIHILATION PROCESS*

Gerson Goldhaber and Wonyong Lee

Experiments on antiproton annihilations in the Lawrence Radiation Laboratory propane bubble chamber[2] indicate that the distribution of the angle between pairs of pions deviates from the predictions of the statistical model. In this work we explored a simple refinement of the statistical model which can explain the bulk of the effect. The refinement[3] consists of taking into account the influence of Bose-Einstein statistics for the pions of like charge. Such an interpretation reproduces the experimental results qualitatively, provided the interaction radius is about 3/4 times the pion Compton wave length.

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

*Work done in collaboration with Sulamith Goldhaber of the Lofgren group and A. Pais of Princeton, N. J.

[2] G. Goldhaber, W. B. Fowler, S. Goldhaber, T. F. Hoang, T. E. Kalogeropoulous, and W. M. Powell, Phys. Rev. Letters 3, 181 (1959).

[3] Gerson Goldhaber, Sulamith Goldhaber, Wonyong Lee, and A. Pais, Influence of Bose-Einstein Statistics on the Antiproton-Proton Annihilation Process, UCRL-9169, Apr. 1960.

INTERACTION OF K^+ MESONS WITH H_2 AND D_2

William Chinowsky, Gerson Goldhaber, Wonyong Lee,
Theodore Stubb, and Bertram Schwartzchild*

A separated K^+ beam[1] was set up at the Bevatron and used in an experiment with the 15-in. hydrogen bubble chamber. We took 200,000 pictures half in deuterium and half in hydrogen. The scanning and analysis of these pictures is progressing satisfactorily. The first aim is to measure the K^+-D charge-exchange cross section ($K^+ + D \rightarrow K^0 + p + p$). This cross section has been observed to rise rapidly from threshold. Other measurements in progress are the pion production cross sections,

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

In addition, work on the K^0 K^+ mass is in progress.

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*In conjunction with Hugh Bradner (Alvarez group), Sulamith Goldhaber (Lofgren group), and Donald Stork and Harold Ticho of UCLA.

[1] Gerson Goldhaber, Sulamith Goldhaber, John Kadyk, T. F. Stubbs, Donald Stork, and Harold K. Ticho, Separated K^+ Beams, Bev.-483, Feb. 1960.

Segrè

ACCELERATOR OPERATION AND DEVELOPMENT

BEVATRON

Edward J. Lofgren in charge

The report for November 1959 through January 1960 has been issued separately as "Bevatron Operation and Development. XXIV", UCRL-9220.

184-INCH CYCLOTRON

Robert L. Thornton in charge

Reported by James T. Vale

No material was received for this section.

60-INCH CYCLOTRON

W. B. Jones in charge

OPERATION

Summary of Usage

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

Alpha bombardments	1,703.4 hr
Proton bombardments	447.7 hr
Deuteron bombardments	235.7 hr
Experimental bombardments	111.5 hr
Operations total	2,498.3 hr
Outage	272.4 hr
Available time	2,770.7 hr
Shutdown	1,469.3 hr
Holidays	128.0 hr
Total Time	4,368.0 hr

An operating efficiency of 90.2% was maintained throughout this 6-month period.

HEAVY-ION LINEAR ACCELERATOR

Chester M. Van Atta in charge

Reported by Edward L. Hubbard

Steel shielding was put over the top of the accelerator and along the south side of it, and a concrete roof was put on the target area. Installation of the shielding made it necessary to shut down the accelerator on day shift for three weeks. Operation for experimenters was reduced from 18 shifts a week to 13 shifts a week on January 1. One shift each week was used for maintenance, repairs, and modifications of the accelerator and experimental facilities.

Operating time was divided among experimental groups as follows:

Chemistry		90.0%
Heavy elements	29.1	
Coulomb excitation	15.2	
Nuclear reactions(Harvey)	8.7	
Fission counting (Larsh)	6.1	
Nuclear reactions (Igo)	2.9	
Other	28.0	
Physics		3.3%
Medical Physics		6.7%

SYNCHROTRON

Rudin M. Johnson in charge

OPERATION AND DEVELOPMENT

A. Synchrotron

During this period the last physics experiment was performed on the synchrotron with the 4-in. hydrogen bubble chamber. The beam was varied from full energy (340 Mev) to half energy, with a maximum intensity of 10^9 electrons per pulse. The machine was mothballed, by decision of Dr. McMillan and the AEC, as a measure to conserve manpower and funds.

The month of November was devoted to injection studies using the electron linear accelerator. A maximum of 50 ma of electrons from the linear accelerator was applied to the inflector system at approximately 2 Mev. With pickup probes inside the doughnut we observed 3 ma out of the inflector, 2 ma at a point 1/3 around, and 1 ma at a point 2/3 around. All attempts to measure beam more than 1 turn around or to accelerate with rf failed.

During December and January a hydrogen bubble chamber experiment was run ($\gamma + d \rightarrow \pi^+ + 2n$, or $\gamma + d \rightarrow \pi^- + 2p$), ending in the calibration of the Cornell shower chamber.

The synchrotron was mothballed during February and March. That is, all spare parts and equipment vital for operation of the synchrotron were stored in cabinets in the magnet room. All other equipment and parts not unique were returned to stock or salvaged. Building 25 was cleared for use by other departments (88-Inch Cyclotron, Accelerator Technicians, etc.).

In the middle of April word was received from the AEC that they had no further use for the synchrotron and that the Laboratory was free to use it as it saw fit. As a result we are now disconnecting the synchrotron and moving it out of the building to a concrete pad and shelter where it will be stored for possible future display in the Lawrence Hall of Nuclear Science. The capacitor bank and power supply will remain intact for use by Dr. Glaser for the xenon bubble chamber magnet supply.

Summary reports are being written on the final operation and development of the synchrotron.

B. Electron Linear Accelerator

The electron linear accelerator was operated during this period for chemistry experiments, mainly for people in Chemistry and Donner Laboratory. The beam intensity was varied from a maximum of 50 ma at 5.5 Mev to lower values, depending on the experimenter's requirements.

Gil Mains, with Dr. Newton's Group, ran extensive irradiations on methane gas and other organic gases at room temperature and 260° C. This is a study of free-radical reactions in radiolysis of gas.

Dr. Garrison and Dr. Jayko irradiated gelatin to study peptide-bond cleavages during this period.

For Brustad and Gardner, bacteriophage and lysozymes were irradiated at liquid nitrogen temperature to study free-radical migration.

Dr. Lemmon and Dr. Punamperuma irradiated uridylic acid to study bond cleavages.

Dr. Lemmon and Dr. Smith irradiated choline chloride made with C^{14} to make free-radical studies.

Dr. Lemmon and Dr. Palm irradiated mixtures of CH_4, NH_3, H_2, and H_2O to study radiation-induced synthesis of organic compounds.

Dr. McLaren and Dr. Luse of Soil Sciences sterilized soil to be used in a study of soil enzyme activity.

Also the magnet bending system and vacuum chamber were installed in the vault in preparation for Dr. Kenney's experiment on polarization of bremstrahlung.

HEALTH PHYSICS*

Burton J. Moyer in charge

RADIATION SURVEY WORK AND RESEARCH PROJECTS

1. As is usual, our primary concern has been the measurement of the radiation field of the Bevatron. During the past six months, in addition to the continuing survey work within the building, we have completed a study of the Bevatron radiation field at distances up to 1500 feet.

This study had a twofold purpose, First, to determine the distance dependence of the radiation; and second, to determine the attenuation in concrete of Bevatron neutrons as a function of distance and position.

2. Preliminary plans were completed by the architect for a new Health Physics building, but at the end of this report period AEC approval was still pending.

3. Cobalt-60 fast-neutron flux integrators have been installed at several locations around the Laboratory. These detectors consist of a disk of cobalt, moderated with paraffin, in an assembly contained within a cadmium jacket. Measurement of the radioactivity induced in the cobalt permits the integration of fast-neutron fluxes as low as 1 n/cm^2-sec over the period of one year.

4. A new kind of fast-neutron monitor has been constructed and put into operation at the Bevatron. The detector consists of a silver foil wrapped around a Geiger tube and enclosed in a paraffin moderator and cadmium jacket. The radioactivity induced in the silver foil by fast neutrons moderated in the paraffin is detected as Geiger tube pulses. These pulses are amplified, sent to a decimal scaler system, and displayed on four nixie tubes and a register. The scaler is gated off during the Bevatron acceleration cycle. The scaler either can integrate the total number of counts over some period of time, or can be automatically reset to zero after each Bevatron pulse.

5. Work has continued on a small plastic-walled integrating ionization chamber, and it is hoped that this instrument will soon be ready for use in environmental monitoring.

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*Report period October 1959 through March 1960.

PAPER PUBLISHED

1. Cosmic-Ray Neutron Energy Spectrum, Phys. Rev. 116, 445-457 (1959).

SUMMARY OF BETA-GAMMA AND NEUTRON READINGS

The personnel-monitoring program has expanded to follow the growth and increased activity of the Laboratory: 2400 beta-gamma and slow-neutron films and 800 fast-neutron films are processed per month.

Combined monthly neutron and gamma exposures

Building or area	Exposure (rem)				
	>0.5	> 1.0	>1.5	>2.0	>3.0
184-inch	1	0	0	0	0
60-inch	24	5	3	1	0
51	7	2	1	0	0
70	2	0	0	0	0
71	2	0	0	0	0
Other	19	3	2	0	0
Total	55	10	6	1	0

Moyer

Technical Info. Div.
CA

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