UCRL 3223

UNIVERSITY OF CALIFORNIA

Radiation Laboratory

PHYSICS DIVISION QUARTERLY REPORT

August, September, October 1955

TWO-WEEK LOAN COPY

This is a Library Circulating Copy which may be borrowed for two weeks. For a personal retention copy, call Tech. Info. Division, Ext. 5545

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

UCRL-3223
Physics Distribution

UNIVERSITY OF CALIFORNIA
Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

PHYSICS DIVISION QUARTERLY REPORT

August, September, October 1955

December 1, 1955

Printed for the U.S. Atomic Energy Commission

PHYSICS DIVISION QUARTERLY REPORT

August, September, October 1955

Contents

GENERAL PHYSICS RESEARCH

Physics Research: Alvarez

Liquid Hydrogen Bubble Chambers 4
K-Meson Lifetimes 6
The Reaction $C^{12}(p,\alpha)B^9$ with 32-Mev Protons 6

Physics Research: Barkas

The Masses of Positive K Particles. I. Identification of K Particles and Analysis of Secondaries 8
The Masses of Positive K Particles. II. Method, Analysis, and Results 9
High-Velocity Particle Ranges in Emulsion 10
Low-Energy Neutron Yields from 200-Mev Proton Bombardment of Carbon, Aluminum, Nickel, Silver, and Gold 10
Angle and Energy Distributions of Charged Particles from the High-Energy Nuclear Bombardment of Various Elements. . 11
Polarization and Angular Distribution of Bremsstrahlung. . . . 11
Interactions of 5.7-Bev Protons in G.5 Emulsion. 12

Theoretical Group: Judd

Physics Research: Lofgren

Elastic Proton-Proton Scattering 16
Terminal Observations on "Antiprotons" 17
Interactions of Negative K Particles at Rest 18
Determination of the K^- Mass by a Range-Momentum Method . . 18

Physics Research: Moyer

Scattering of 100-Mev to 145-Mev Gamma Rays by Protons . . . 26
Neutron Yields at the Linear Accelerator 27
Bismuth Fission Chamber 27
Neutral Mesons Produced in Proton-Proton Collisions 28
Positive-Pion Total Cross Sections at High Energies 28
Paper Submitted 29

Cloud Chamber Studies: Powell

Proton-Proton Interactions at 5.3 Bev 30
Multiple Pion Production in n-p Collisions at the Bevatron . . . 30
π-p Interactions at 4.5 Bev 31
Geneva Cloud Chamber 32

Physics Research: Richman

Negative Proton Experiment 33
Mass Values of Indentified K Mesons 33
One Hundred Bevatron τ^+ Mesons 34

* Preceding Quarterly Reports: UCRL 3115, UCRL-3014

Spiral-Orbit Spectrometer: Sagane

Physics Research: Segrè

p-p Polarization: Measurement of the Depolarization Coefficient A 37
Polarization in Proton-Carbon Scattering from 141 Mev to 314 Mev 37
Antiprotons 37
Decay Modes of Negative K Mesons 40
Interactions in Flight of K^- Mesons 40

ACCELERATOR OPERATION AND DEVELOPMENT

Bevatron 42
184-Inch Cyclotron 42
60-Inch Cyclotron 43
Linear Accelerator 45
Synchrotron 46

PHYSICS DIVISION QUARTERLY REPORT

August, September, October 1955

Radiation Laboratory
University of California
Berkeley, California

December 1, 1955

GENERAL PHYSICS RESEARCH

PHYSICS RESEARCH

Luis W. Alvarez in Charge

LIQUID HYDROGEN BUBBLE CHAMBERS

Luis W. Alvarez, James D. Gow, and group

General

Work on the four- and ten-inch chambers has continued to occupy the major share of the group effort during this quarter. Effective October 1, several components of the 72-inch chamber were released for final engineering design and construction. Owing to budget restrictions, a change in the order of engineering and construction of the large-chamber components has been made. It is planned to first build the vacuum envelope, the N_2 and H_2 shields, the chamber proper, and an expansion system. This will permit tests of the full-scale cryogenic system and preliminary operation of the device as a bubble chamber. The construction of the magnet, carriage, and certain other auxiliaries necessary to find operation will be delayed.

Test Programs

A test program to determine the consequences of the sudden release of substantial quantities of liquid hydrogen into an evacuated enclosure has been completed and a report written (UCRL-3136). The window-seal test work has been reoriented toward the problem of sealing the 72-inch window. Measurements on the strength of glass at low temperature are being made at the NBS Boulder Cryogenic Laboratory, to yield the engineering information necessary to permit design of the large window.

Several experiments relating to the proper design of normal and emergency hydrogen-vent systems have been made, and considerable design effort has been placed on the safe disposal of hydrogen. The results indicate that hydrogen should be ignited upon release. Burning eliminates the possibility of a subsequent explosion.

A series of tests simulating window failure have shown that glass fragments of the order of 1 cubic inch can be produced and accelerated to rather high velocities. It is necessary to provide shatterproof viewing windows in

the vacuum vessel to prevent the possibility of chamber-window failure from releasing hydrogen into the air. An inner window shield of lucite has been demonstrated to be satisfactory. Various other tests on the properties of materials at low temperature have been made.

Status of 4-inch Chamber

As a result of experience in the synchrotron run, a new stainless steel chamber with improved window flanges and double lead gaskets was made and installed.

The redesigned chamber can be operated at pressures as high as 150 psig without leakage. A temperature-regulation system was put into operation and a series of "engineering" runs was made with the chamber. In the course of the test runs, it was determined that the regenerator is ineffective on the expansion part of the pressure cycle. Gas enters the expansion cylinder at a temperature as low as -150°C. Repressurization of the chamber after expansion has been shown to be due to heating of cold gas in the cylinder.

A gas-handling and -recovery system was set up to permit operation of the chamber with deuterium. A run was made and tracks were produced in D_2. At the end of October the chamber was being made ready for a series of runs at the Bevatron.

Analysis of the synchrotron run pictures has demonstrated that a hydrogen bubble chamber is a very suitable instrument for study of high-energy x-ray-induced reactions.

Status of 10-Inch Chamber

The 10-inch chamber has been completely assembled and tested with liquid nitrogen. Radiation sensitivity of the N_2 was obtained. All of the electronic control system worked satisfactorily, as did the cryogenic and pressure systems. Cool-down rates for all parts were satisfactory. Measurements of the static boil-off rates from the various Dewars were made. The chamber was being set up, at the end of October, for its first run with H_2. The hydrogen test has been delayed by the necessity of redesigning the illumination system and by some electrical modifications required for safety interlocking.

A liquid-phase expansion system is being built. It uses a long thin-walled piston and cylinder with the working end at low temperature and the driven end at room temperature. The new expansion system will be tested in a separate apparatus before it is installed in the 10-inch chamber.

Status of 72-Inch Chamber

Design work on the magnet was stopped after it reached the point where the basic parameters were established. Engineering is proceeding on the cryogenic systems, vacuum vessel, and chamber. Considerable effort has gone into producing reliable cost estimates for the various parts. Experimental work on scale models of the large window seal is under way. Engineering data from the 4-inch and 10-inch chambers are being analyzed and extrapolated to arrive at design numbers for the large-chamber cryogenic performance.

Alvarez

K-MESON LIFETIMES

Luis W. Alvarez, Myron Good, Frank Crawford, M. Lynn Stevenson

The following abstract from the Bullentin of the American Physical Society summarizes the work of this group:

> Since the various species of K mesons produced at the Bevatron have masses equal within the rather small experimental error, it becomes a critical matter to see if the lifetimes of the separate species are the same, or different. A counter experiment to investigate this point is being carried out. K^+ mesons, momentum-analyzed in the magnet arrangement of Kerth and Stork, are detected by a scintillation counter telescope and brought to rest in one of the scintillators. A side counter telescope of four counters detects the decay fragments, distinguishing between $K_{\pi 2}$, $K_{\mu 2}$, and τ decays. In one experiment in which 127 $K_{\mu 2}$'s and 72 $K_{\pi 2}$'s were observed to decay, preliminary results give equal lifetimes for the $K_{\mu 2}$ and $K_{\pi 2}$, approximately 1.3×10^{-8} sec. Results for the τ are not yet clear-cut.

The final results from this run are

$$K_{\pi 2}: 1.3 \pm 0.2 \times 10^{-8} \text{ sec},$$
$$K_{\mu 2}: 1.4 \pm 0.2 \times 10^{-8} \text{ sec}.$$

And for a mixture of K's,

$$K \ : 1.3 \pm 0.1 \times 10^{-8} \text{ sec}.$$

THE REACTION C^{12} (p, α) B^9 WITH 32-Mev PROTONS

H. Brook Knowles

Complete or almost complete range spectra of alpha particles have been taken at laboratory angles of 15°, 30°, and 90°. The ground-state and 2.4-Mev level appear quite clearly at these angles with a strong angular dependence for the ground state, which appears to be reduced by a factor of about 5 in going from 15° to 90°. The 2.4-Mev level appears to be roughly constant and much smaller in the forward direction than the ground state.

Roughly Calculated Sections

	Ground-state (mb)	2.4 Mev (mb)
15°	2.5	0.30
30°	1.5	0.30
90°	0.40	0.30

There is a strong indication of a broad level at about 5 Mev and another at about 7.8 Mev, but these are not resolved clearly from the alpha-particle background from these reactions:

$$C^{12} + p \rightarrow Be^{8*} + \alpha + p \quad \text{(3-body)},$$
$$C^{12} + p \rightarrow 3\,\alpha + p \quad \text{(4-body)},$$
$$C^{12} + p \rightarrow C^{12*} + p \quad \text{(stepwise)}.$$
$$\searrow Be^{8*} + \alpha$$

The sharp rise of the background under the 2.4-Mev B^9 level indicates that the 3-body reaction leading to the 3.0-Mev level of Be^8 is quite prolific, as compared to that leading to the ground state of Be^8.

Difficulty has been encountered with beam energy variation during a run, and a project is currently under way to compensate this by adjustment of machine parameters. A multichannel differential range counter is also being designed to increase the efficiency of operation.

PHYSICS RESEARCH

Walter H. Barkas in Charge

THE MASSES OF POSITIVE K PARTICLES. I. IDENTIFICATION OF K PARTICLES AND ANALYSIS OF SECONDARIES*

Frances M. Smith, Harry H. Heckman, and Walter H. Barkas

Our program on the measurement of meson masses has now been extended to include several types of K^+ mesons produced by the Bevatron and detected in emulsion. In order to identify the types of K's involved, the secondaries were analyzed in terms of grain density, range, and multiple scattering.

The τ mesons are easily identified from the three charged pion daughters. The ranges in the emulsion of these secondaries are being measured to obtain an energy spectrum of the secondaries and a Q value for the decay process. This is of particular value as we have carefully determined the density of the emulsion used in this study. We are also completing an experimental determination of the range-momentum relation in the emulsion as a part of the program.

The τ' mesons and $K_{\mu 3}$ particles included in the study were identified by following the secondary to the end of its range. These secondaries have grain densities substantially above minimum and thus have a high probability of stoping in the emulsion stack. Measurement of their ranges enables one to obtain the energy spectra of the secondaries from the τ' and $K_{\mu 3}$.

The grain density at the beginning of the track of the $K_{\mu 2}$ daughter is about 1.05 minimum while that of the $K_{\pi 2}$ is about 1.20 minimum. A reasonable separation was obtained by grain-counting those secondary tracks whose "dip" angles were less than 15°. Scattering measurements were made on the tracks (identified by grain count as being $K_{\mu 2}$ secondaries) that had dip angles up to 10°. The measured scattering angles confirmed that the group of mesons selected by grain density was a sample of $K_{\mu 2}$ particles.

Details on these measurements and on the estimates of the relative population of protons, pions, and the various types of K particles will be presented.

---

* Abstract for the Los Angles meeting of the American Physical Society, December 1955.

THE MASSES OF POSITIVE K PARTICLES. II. METHOD, ANALYSIS AND RESULTS*

Harry H. Heckman, Frances M. Smith, and Walter H. Barkas

K-particle masses were measured by comparing ranges of $K_{\mu 2}$, $K_{\pi 2}$, $K_{\mu 3}$, and τ' mesons with the ranges of τ mesons and protons of the same momentum. For the momentum analysis we have used the Kerth-Stork[1] arrangement, introducing several modifications that enabled us to obtain a mass resolution of 1.6% for an individual particle. The mesons were produced by bombarding a Ta target with 4.8-Bev protons. They had a flight time of about 1.2×10^{-8} sec. before entering the detector, a stack of nuclear track emulsion. The scanning procedure was to traverse the emulsion 1.5 cm from the calculated depth of penetration for τ mesons, and to follow particles that fulfilled criteria of grain density and direction to the ends of their ranges. The data recorded for each K particle included the mode of decay, the range (measured along the track), and the position of entrance into the stack. The mass differences of the K mesons were calculated from the differences in the mean ranges of each type of particle. We have obtained the following masses, in units of the electron mass, when the mean of the τ mass is taken to be 966:

τ (966 ± 3.1), $K_{\mu 2}$ (962.5 ± 3.2), $K_{\pi 2}$ (972.2 ± 4.7),
$K_{\mu 3}$ (951.2 ± 10.6), τ' (951.5 ± 10.9).

If the particles are compared directly with protons of the same momentum, the masses are in close agreement with those measured relative to the τ mass, indicating that the shape of the range-momentum relation[2] is nearly correct and that the systematic errors are small.

---

* Abstract for the Los Angles meeting of the American Physical Society, December 1955.

1 Birge, Haddock, Kerth, Peterson, Sandweiss, Stork, and Whitehead, Phys. Rev. 99, 329 (1955).

2 Walter H. Barkas and D. M Young, "Emulsion Tables. I." University of California Radiation Laboratory Report No. UCRL-2579 (rev), May 1954.

HIGH-VELOCITY PARTICLE RANGES IN EMULSION*

Walter H. Barkas, Paul H. Barrett, Pierre Cüer, Harry H. Heckman, Frances M. Smith, and Harold K. Ticho

The range-velocity relations for all stopping materials are at present considered unreliable at high particle velocities because of recent evidence[1] that the mean ionization potentials are seriously in error. The situation is particularly intolerable for nuclear track emulsion, because important questions regarding the masses and decay schemes of K particles and hyperons depend on accurate energy determinations from the measured ranges of secondaries. A complication in emulsion is that for this material the density must be determined before the material is specified adequately. We have exposed emulsion blocks of accurately measured density to pions and protons for which the momentum is known to about 1 part in 1000. The momentum is measured by 180-degree bending in a magnetic field. Several points on the range curve at equivalent proton energies of up to 800 Mev have been measured to a precision of better than one percent. More ranges are being measured in an effort to reduce the statistical error.

LOW-ENERGY NEUTRON YIELDS FROM 200-Mev PROTON BOMBARDMENT OF CARBON, ALUMINUM, NICKEL, SILVER, AND GOLD

Edward E. Gross

Absolute yields have been determined by monitoring thin foils placed over the front and back surfaces of the targets exposed to the internal cyclotron beam. A stack of foils, including guard foils and polyethylene foils, was then exposed at the same cyclotron radius and monitored in the same geometry as the foils on the targets. A known number of 340-Mev protons was then passed through polyethylene foils and again monitored in the same geometry. On the basis of the known excitation function for C^{11} activity, the number of protons through the internal foils could then be calculated. Excellent agreement was obtained between several calibrations and a calibration based upon the 15-hour activity from proton bombardment of Al.

As reported previously, little or no angular variation in the yield of neutrons from Ag and Au was observed for the angular interval 135° to 45° and energy interval 0.5 Mev to 10.0 Mev. Since then a noticeable increase in the yield of neutrons from Ni has been observed in going from 90° to 45°. For Al there is a noticeable increase in neutron yield from 135° to 90° and from 90° to 45°. Preliminary results for C indicate a more pronounced variation.

---

* Abstract for the Los Angeles meeting of the American Physical Society, December 1955.

1 D. O. Caldwell, Nuovo Cimento 2, 183 (1955); L. Vigneron, J. Phys. radium 14, 145 (1953).

ANGLE AND ENERGY DISTRIBUTIONS OF CHARGED PARTICLES FROM THE HIGH-ENERGY NUCLEAR BOMBARDMENT OF VARIOUS ELEMENTS

Evan Bailey

The means of determining the absolute cross sections in these experiments has been improved. To do this three cyclotron runs were made:

1. A bombardment of a ribbon target at the 60-inch cyclotron radius to produce secondaries, which are analyzed.
2. A bombardment at the 60-inch cyclotron radius of a stack made up of groups of three identical foils arranged in the following order; polyethylene (carbon), aluminum, nickel, silver, gold, and polyethylene.
3. A bombardment, by the full-energy external cyclotron beam, of three ployethylene foils. For this run the beam was collimated by a 3/4-inch diameter brass tube, was passed through the foils placed 37 inches behind the collimator, and was collected and integrated by a Faraday cup placed 26 inches behind the foils. The distance between the collimator and foils and that between the Faraday cup and foils were chosen to be large so as to minimize activity caused by secondary neutrons (and charged particles) traversing the foils Large numbers of these unwanted secondaries originate in the collimator and in the Faraday cup.

The foils bombarded in these runs were counted for beta and gamma activity. The foils of runs No. 2 and No. 3 were bombarded in groups of three so that the outer two served as guard foils. By use of counting rates measured after these three runs and of published excitation functions of the $C^{12}(x, xn)C^{11}$ reaction, the number of particles through the target in Run 1 can be computed.

The method of determining absolute cross sections is similar to that described above by E. E Gross, and some of the work was done in collaboration with him.

The formula that is generally employed to calculate the differential cross sections for the production of various secondary particles from the observed density of their tracks in emulsion is strictly valid only for a uniform magnetic field. The correction required because the field is nonuniform has been computed by a numerical integration along various secondary orbits.

The work of computing cross sections from the data is nearly complete.

POLARIZATION AND ANGULAR DISTRIBUTION OF BREMSSTRAHLUNG

John M. Dudley, Robert W. Kenney, and Fred W. Inman

An attempt has been made to observe the polarization and angular distribution of bremsstrahlung from 24-Mev electrons passing through a 0.001-inch aluminum foil. The experiment was carried out at Stanford University on the

Barkas

Mark II linear accelerator. The method of detection was the use of C.2 nuclear emulsion plates loaded with D_2O. We concluded, after scanning more than 300 tracks, that most of the tracks were due to neutron-proton collisions. Methods of eliminating this background were investigated, and the experiment was performed again with about 3000 lb of paraffin as neutron shielding. The plates exposed in the latest run are processed at the time of writing of this report, but have not been scanned extensively. Tracks that meet the selection criteria appear in the emulsions.

INTERACTIONS OF 5.7-Bev PROTONS IN G.5 EMULSION

Peter C. Giles

On August 18 three emulsion stacks were exposed at the Bevatron directly in the circulating proton beam. They were exposed to protons of different energies; one stack at 2 Bev, one at 4.1 Bev, and one at 6.2 Bev. The stacks consisted of fifteen 600-micron G.5 emulsions pellicles each. The exposure was made while Professor Pierre Cüer was visiting Berkeley in order to provide him with emulsions for research in Strasbourg.

In a stack exposed to 5.7-Bev protons in the Bevatron 0.2 cc of emulsion has been carefully scanned. The protons were incident normal to the planes of the pellicles. About 330 interactions have been found, with a mean free path of 34 centimeters. A large number of apparent "scatters" are found, with no recoil particle. It is presumed that these are interactions with peripheral neutrons. The angular distribution for these events is being measured. Five events whose space angles are consistent with proton-proton scattering have been found. From these events a total p-p elastic cross section of 13 ± 6 millibarns is calculated. None of the space angles of these events are consistent with those calculated for the reaction $p + p \rightarrow \pi^+ + d$.

THEORETICAL GROUP

David L. Judd

The long $K_{\mu 2}$ lifetime and the absence of a K_{e2} decay mode can be explained by using for $K \rightarrow \mu + \nu$ the same interaction that has been invoked to explain the absence of $\pi \rightarrow e + \nu$ in $\pi \rightarrow \mu + \nu$ decay. Radiative decays $K \rightarrow \mu + \nu + \gamma$, $K \rightarrow e + \nu + \gamma$ are important and account for some, but not all, of $K_{\mu 3}$, K_{e3} observed. A paper is being prepared for publication. (Sidney Bludman)

Beta decay has suggested that μ^+ and e^- are the normal particles and μ^- and e^+ are antiparticles. This identification, together with charge conservation, can be used to absolutely forbid $\pi - e$ decay while alowing $\pi - \mu$ decay, if--as Finkelstein has argued--a distinction can be made between processes like $n \rightarrow p + e^- + \bar{\nu}$ and $n + \bar{p} \rightarrow e^- + \bar{\nu}$. Such a distinction does not appear justified, however, by field theory, according to which the same operator that creates protons must annihilate antiprotons. (Sidney Bludman)

Work is continuing on the statistical theory of high-energy events, particularly attempting to include angular-momentum conservation. The statistical model has recently been used to calculate relative probabilities of antiproton annihilation with emission of two, three, and four pions. (D. H. Holland)

The isotopic spins of antineutron and antiproton are usually taken as +1, -1 respectively. A note has been written to point out that these numbers are not the eigenvalues of the isotopic spin operator τ_3 associated with these particles, but their negatives. This conclusion emerged from an investigation whose aim was to see if there was any ambiguity in the isotopic spin eigenvalues associated with antinucleons. (Joseph V. Lepore)

A paper on the generalized effective range theory of scattering and the implications of the Lomon-Feshbach analysis of nucleon scattering data is being published. A second paper on a method of deducing properties of the nuclear force from the scattering data is being written. Higher approximations in this method are also being worked on. (Robert Raphael)

The small-angle scattering and polarization of high-energy protons scattered elastically from carbon was examined in terms of the optical model of nucleon-nucleus scattering. It was found necessary to include an imaginary spin-orbit potential with the usual nuclear potential (central plus real spin orbit) to fit the experimental polarization. It can be shown that the imaginary spin-orbit potential implies lack of conservation of the angular momentum of the incident particle. In addition, the inclusion of relativistic Coulomb effects enables one to establish the sign of the spin orbit potential from the experimental scattering data alone. A paper reporting on this work has been submitted to the Physical Review. (Warren Heckrotte)

An attempt is being made to extend the methods of Goldberger (Phys. Rev. 99, 979 (1955)) to derive some dispersion relations for boson-fermion scattering, which would apply to the case of a fixed, finite momentum transfer between the two particles. The principal difficulty seems to be in discovering

the physical significance of the analytic continuation of the scattering matrix to real energies smaller than the minimum energy necessary to allow the momentum transfer. (Richard Capps)

An investigation is being started concerning the effects of an interaction between pi mesons on various phenomena involving nucleons and pions. (Richard Capps)

A best theoretical guess was made to answer "what does the antiproton annihilate into?" We assumed (a) annihilation takes place at small distances ($\approx M^{-1}$, the nucleon Compton wave length), and (b) the mesonic nucleon-antinucleon force is at least qualitatively described by the one-meson-exchange term. Assumption (a) implies that the decay multiplicity will be small, and that there will be a strong centrifugal barrier effect on both initial and final states. That is, absorption will be from S states, and decay states with few particles, having low angular momenta, will be favored. Hence the probable annihilation products from a given initial state can easily be deduced. It is interesting that K mesons are expected in some cases. Assumption (b) implies that the S-state nucleon-antinucleon potentials will be ranked in order of increasing depth, so ${}^1_3S$, ${}^3_1S$. ${}^3_3S$, ${}^1_1S$ (lower index--i-spin state); only the last yielding "nuclearly bound protonium." But decay will be from this unique state only if annihilation is slow enough (e.g., if the annihilation region is shielded by a hard core of the nuclear force) to allow cascade down to it. In nuclei the situation is complex, but the annihilation products (except photons) will be in any case highly disguised. In hydrogen the electromagnetic cascade seems to fill all the S states (but ${}^1_3S$), and MD transitions to ${}^1_1S$ can compete with annihilation only if the latter is inhibited by a factor of 10^{3-4}. (Charles Goebel)

By use of the isotopic spin assignments for "strange" particles according to Gell-Mann, the relative rates for associated production, with or without the production of an additional pion, were computed. As the experimental conditions for checking these are almost impossible (K mesons of a specific energy have to be observed sufficiently close to threshold to prevent production of more pions) these reactions are clearly not as useful for checking the i-spin assignments as the K^--absorption experiments. (University of California Radiation Laboratory Report No. UCRL-3074) (Stephen Gasiorowicz)

A study of the application of the Laudau approximation (Doklady Akad. Nauk. S.S.S.R. 95 (1954)) to fixed-source theories has been undertaken. In the neutral scalar theory the Laudau solution agrees in the relevant region (weak coupling) with the exact solution. (Stephen Gasiorowicz)

Work is in progress on the calculation of cross sections for production and decay of "strange" particles. Only "strong" reactions, on the basis of the Gell-Mann classification, are being considered. (Richard Spitzer)

The calculation of single particle energy levels and wave functions in a deformed nuclear potential, mentioned in the last progress report, is still in progress and nearing completion. An investigation of the effective moments of inertia of rotating deformed nuclei has also been begun in cooperation with Dr. David R. Inglis. (Marvin Rich)

Judd

Considerable attention has been given to a miscellaneous assortment of problems connected with recent developments in particle accelerator theory. Two reports on the MURA FFAG proton synchrotron beam dynamics were written during a summer visit at the MURA project. Some thought has been given to spiral ridged FM cyclotron parameters and to tolerance problems in AGS machines. A summary of early theoretical work on Thomas-type cyclotrons done at Berkeley in 1950-52 is being prepared. (David L. Judd)

PHYSICS RESEARCH

Edward J. Lofgren in Charge

ELASTIC PROTON-PROTON SCATTERING

Bruce Cork and William A. Wenzel

Measurements of the differential cross section for elastic proton-proton scattering as a function of angle and energy have been extended to smaller angles. The absolute calibration of the cross-section measurements has been improved.

Experimental results to date are as follows:

T (Bev)	θ (cm)	$\frac{d\sigma}{d\omega}$ (mb/steradian)
0.92	49.4	3.3
	72.1	.76
	91.7	.45
2.24	23.4	12.1
	29.2	7.7
	44.0	1.5
	57.6	.58
	70.3	.33
	93.5	.19
3.49	34.2	1.7
	49.2	.26
	64.4	.07
	78.5	.06
4.40	17.5	15.6
	28.5	2.6
	35.4	.54
	37.5	.61
	53.2	.12
	69.0	.045

The uncertainty in the absolute values is about ± 30%. The experiment is being extended to still smaller angles and to higher energies.

TERMINAL OBSERVATIONS ON "ANTIPROTONS"

John M. Brabant, Bruce Cork, Nahmin Horwitz, Burton J. Moyer, Joseph J. Murray, Roger Wallace, and William A. Wenzel

Particles of mass 1840 ± 90 m_e have been detected in the negative 1.2-Bev/c beam from the Bevatron by Chamberlain, Segrè, Wiegand, and Ypsilantis.[1] Their experimental facilities will be referred to as "A". This report deals with an experiment performed in conjunction with "A" to obtain further information on the nature of these particles.

The particles in question leave "A" with about 500 Mev kinetic energy. They enter a large lead-glass Cerenkov counter,[2] which is suitable for the production and detection of electron showers that would result from π^o emission in the annihilation process of an antiproton.

The distribution of pulses from particles selected by "A" displays a greater relative population in the region of large energy release than is characteristic of the distribution from the negative pions that enter the counter, and the upper limit of the "A"-selected distribution is higher than the largest pion-produced pulses.

The transmission of "A"-selected particles by a 2.5-inch copper absorber with a detector subtending 0.05 steradian at the absorber indicates an attenuation cross section of 1.7 ± 0.7 geometric ($R_{geometric} = 1.25 \cdot 10^{13} A^{1/3}$ cm). The transmission of "A"-selected particles by the lead glass of the counter yields a lower limit for the cross section for interaction with large energy release of 1.9 ± 0.6 geometric.

A fuller account of this work has been submitted to the Physical Review for publication.

[1] O. Chamberlain, E Segrè, C.E. Wiegand, T.J. Ypsilantis, Phys. Rev., in press.

[2] R. Wallace, M.H.L. Jester, J.M. Brabant, Bull. Am. Phys. Soc. 30, No. 5, 16 (1955).

Lofgren

INTERACTIONS OF NEGATIVE K PARTICLES AT REST*

Warren W. Chupp and Sulamith Goldhaber

The analysis of 132 K^--meson interactions at rest has been continued.[1] In those interactions we identified 33 $\pi^\pm$ mesons, 14 $\Sigma^\pm$ hyperons, and 3 hyperfragments. Five of the π mesons were associated with Σ hyperons. A measurement of the ranges and the ionization (for π mesons not ending in the stack) of π mesons permitted us to obtain an energy spectrum given in Fig. 1. Similarly, a measurement of the ranges of the protons emitted in the absorption stars and ionization measurements on protons leaving the stack allowed us to construct an energy spectrum given in Fig. 2. An energy spectrum for the charged hyperons is shown in Fig. 3.

DETERMINATION OF THE K^- MASS BY A RANGE-MOMENTUM METHOD*

Warren W. Chupp, and Sulamith Goldhaber

This experiment was designed to obtain the K^- mass relative to the K^+ mass. For this purpose we exposed a stack of pellicles in the focused and momentum-selected K^+ beam[2] centered at about 325-Mev/c momentum. Behind the K^+ stack (see Fig. 4) we placed a suitable Cu wedge absorber, placing three pellicles in the wedge. The wedge absorber permitted us to stop the π^+ mesons whose average momentum corresponds to that of the K^+ meson incident on the central plate of the stack. An exposure under similar conditions was carried out consecutively for K^-mesons, reversing the magnetic field in the strong-focusing spectrometer system. The π^- mesons were also stopped by the same Cu wedge We partially compensated for the effect of the stray field of the Bevatron on the strong-focusing spectrometer system. That it was only a partial compensation accounts for the difference in ranges of the π^+ and π^- obtained experimentally. This difference in the π ranges and the knowledge of the π^+ momentum permitted us to calculate the average π^- momentum. This momentum then corresponds to the central plate of the K^- stack. Knowing the momentum of the K^-mesons and their experimental ranges, we were able to obtain the K^-mass. It should be mentioned that the K^+ momentum was obtained from the experimentally determined K^+ ranges and taking the mass of the K^+ mesons to be equal to the τ mass = 965.4 m_e. It should be pointed out that the above method does

---

* This work has been done in conjunction with Gerson Goldhaber and Francis H. Webb.

1 Edward J. Lofgren and Harry G. Heard, Bevatron Operations and Development. V, University of California Radiation Laboratory Report No. UCRL-3033, August 24, 1955.

2 Robert W. Birge, Roy P. Haddock, Leroy T. Kerth, James R. Peterson, Jack Sandweiss, Donald H. Stork, and Marian N. Whitehead, "Bevatron K Mesons," Phys. Rev. 99, No. 1, 329 (1955).

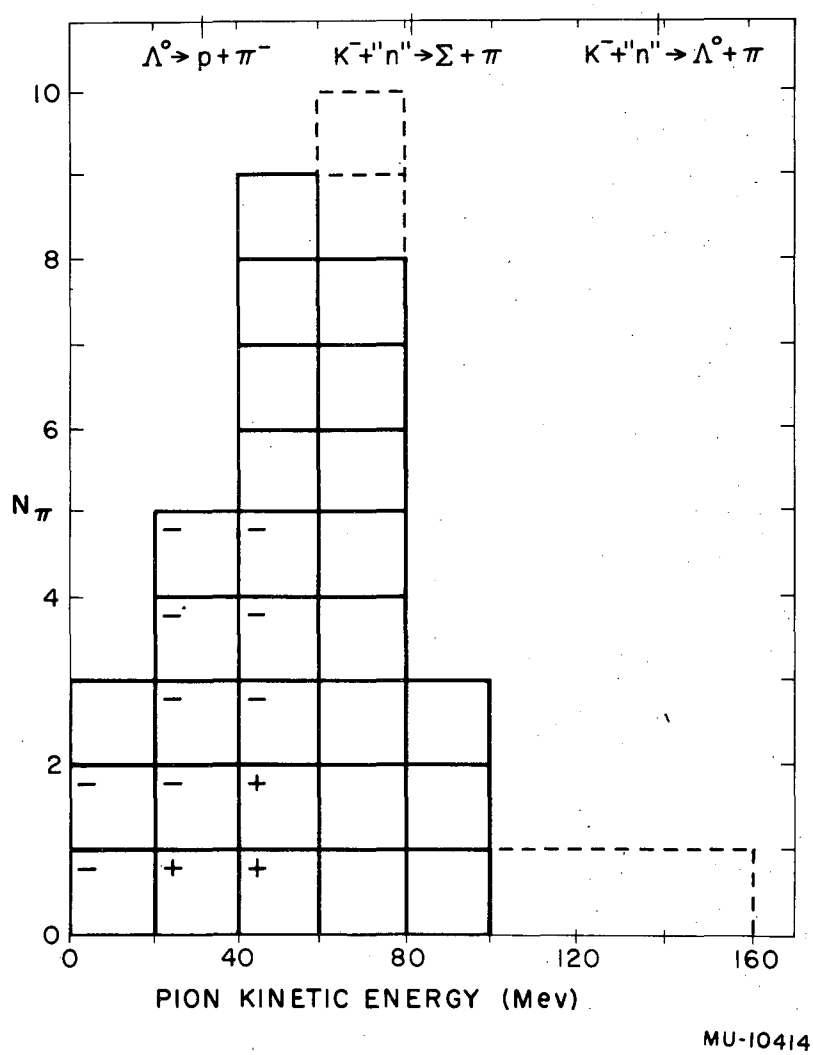

Fig. 1. Energy spectrum of π mesons.

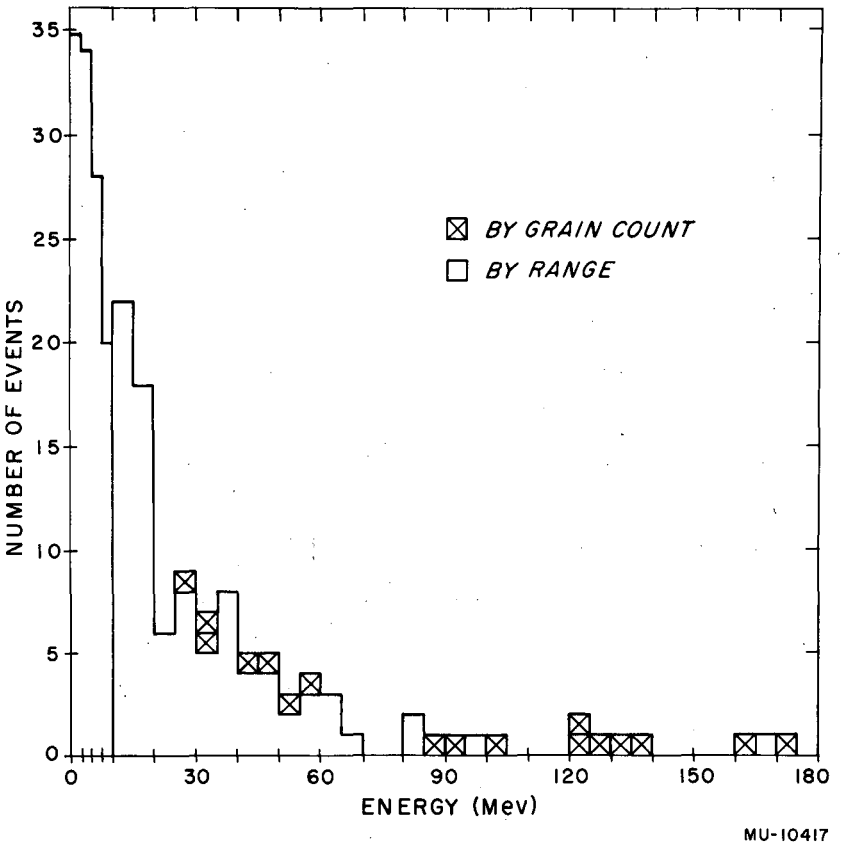

Fig. 2. Energy spectrum for protons.

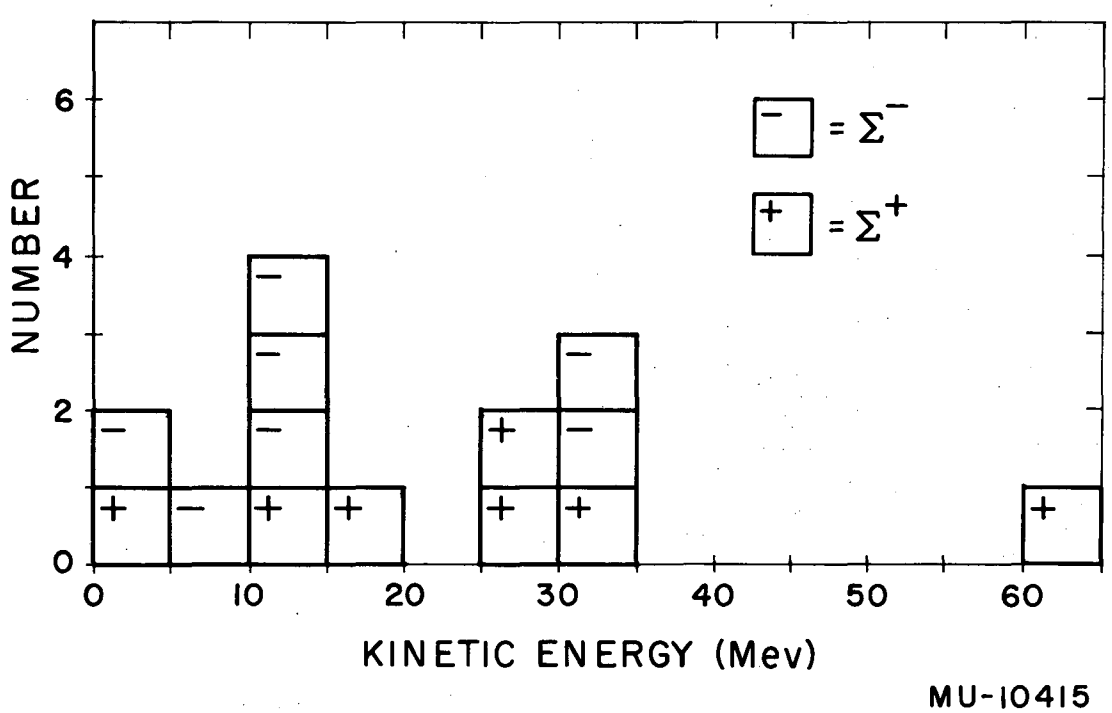

Fig. 3. Energy spectrum for charged hyperons.

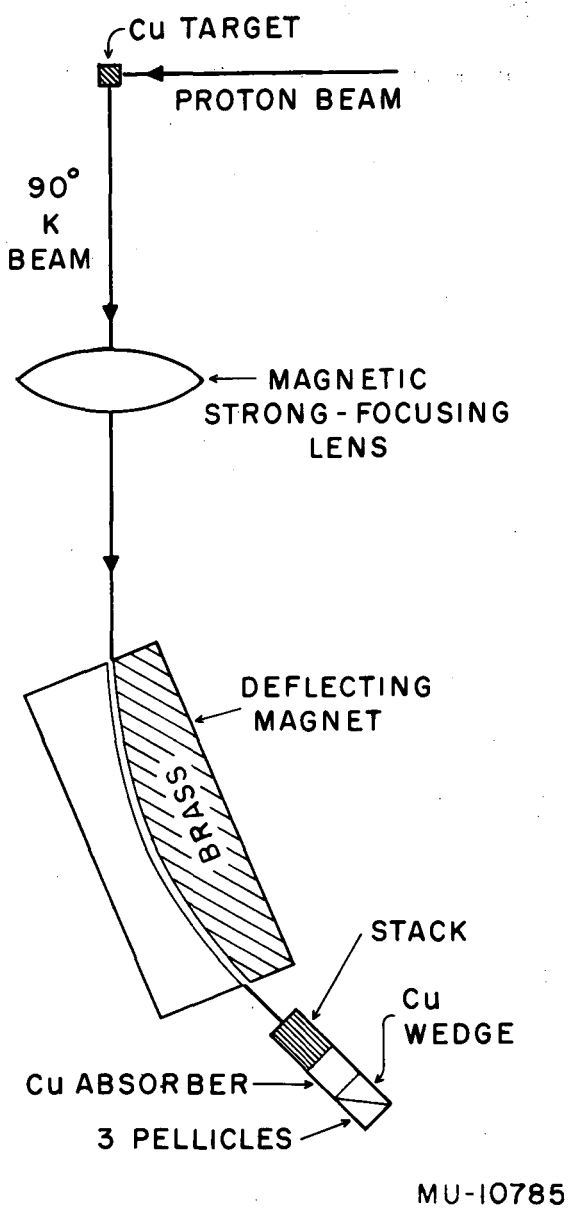

Fig. 4. Equipment for determination of the K^- mass.

not require the knowledge of the range-energy relation, but for going from the momentum of the π^+ mesons to that of the π^- mesons (i.e., 324.3 Mev/c to 315.3 Mev/c, respectively). Figure 5 gives the experimental π^+ and π^- range distribution in the wedge absorber in terms of equivalent range in emulsion. Figure 6 gives the mass histogram for the K^- mesons. The mass of the K^- meson obtained by the method described is

$$M_{K^-} = 963 \pm 12\ m_e$$

The error quoted includes statistical and alignment errors.

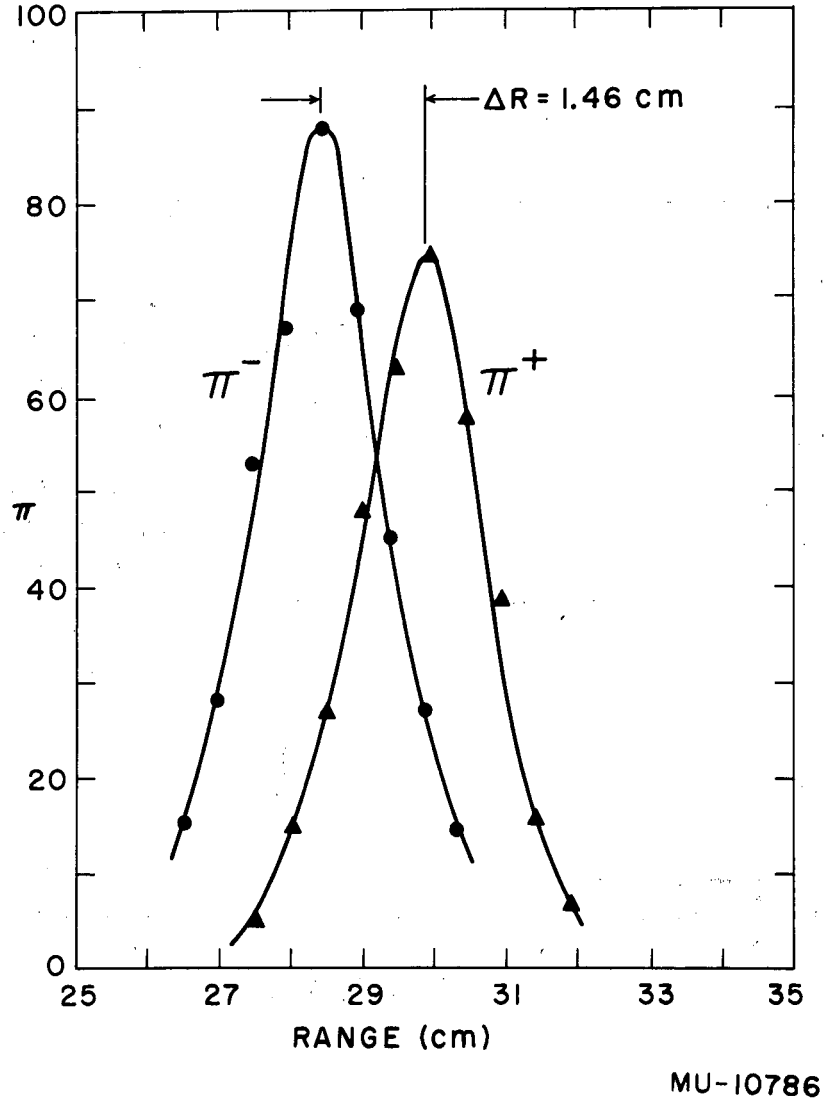

Fig. 5. Range distribution in the wedge absorber (in terms of equivalent range in emulsion).

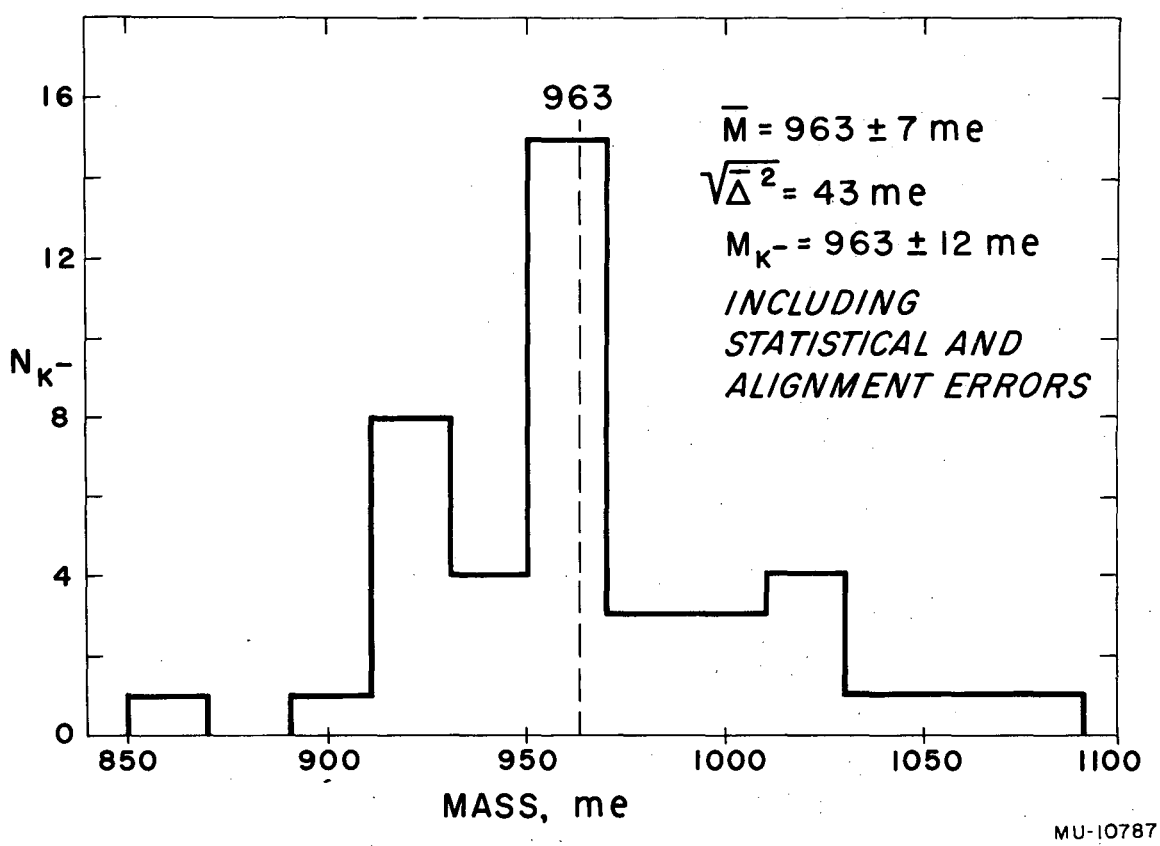

Fig. 6. Mass histogram for the K^- mesons.

PHYSICS RESEARCH

Burton J. Moyer in Charge

SCATTERING OF 100-Mev TO 145-Mev GAMMA RAYS BY PROTONS

Larry L. Higgins

An experiment is in progress at the synchrotron to measure the cross section for the scattering of gamma rays from protons. In order to observe this Compton scattering it is necessary to operate with photon energies below the treshold for π^0 production, otherwise the photons from π^0 decay completely dominate the picture. However, operation above the π^0 threshold is employed in order to normalize the Compton-scattering data below threshold.

A triple-coincidence converter-telescope preceded by an anticoincidence scintillator counter is employed to detect the high-energy elastically scattered photons at 90° from the beam direction. The target is liquid hydrogen with a thickness along the beam of 0.71 g/cm^2 (0.012 radiation length). Preceding the target a sweeping magnet clears the beam of electrons originating in the vacuum chamber wall and collimating fixtures. Under these conditions the counting rate for the Compton-scattering process is about 5 counts per hour.

In order to suppress the effects of scattered electrons from the target a low-Z absorber consisting of Be and carbon was interposed between the target and the detector. Under these conditions the ratio of converter-in to converter-out counts was 5, and the ratio of full-target to empty-target counts was approximately 4. The telescope has an inherent energy threshold which prevents its detection of photons Compton-scattered from the electrons of the target.

All counts were recorded by photographing the sweep of a 517 Tektronix oscilloscope upon which were displayed the pulses from all the counters comprising the telescope and anticoincidence feature. Conditions of pulse height, pulse shape, and pulse spacing serve to discriminate the desired counts against accidentals produced by neutrons and against the sea of gamma rays, electrons, and cosmic rays. The electronic resolution time effective in triggering the oscilloscope sweep was 10^{-8} sec, and the time resolution effective upon examination of the oscilloscope traces was 4×10^{-9} sec.

Because the experiment must be performed with a bremsstrahlung spectrum from the synchrotron it is necessary to achieve energy selection by varying the upper limit of the spectrum. To this end runs have been made utilizing twelve different upper-limit energy values distributed between 80 Mev and 170 Mev. Above 145 Mev the counting rate, of course, rises very rapidly owing to the production of the π^0 mesons.

Data are now being reduced from the oscilloscope traces, and plans are developing for the study of this Compton scattering at angles other than 90°. Results at this stage indicate a cross section approximately equal to the Thompson cross section, with some energy dependence apparent as π^0 threshold is approached.

Moyer

NEUTRON YIELDS AT THE LINEAR ACCELERATOR

Selig Kaplan, George P. Millburn, Burton J. Moyer, and Y. K. Tai

Measurements of the neutron yields from thick targets bombarded by 32-Mev protons have essentially been completed, and a program to separate the yields into two energy regions, 32-18 and 18-0 Mev, has been begun.

The essential features of the results for 0- to 32-Mev protons are two abrupt jumps of a factor of two in the yields at Z = 20 and Z = 30, with also a decrease by a factor of three in the yield from Ni compared with Co and Cu. For Z < 30, the yields show a variation with neighboring even-even and odd-even nuclei. Systematic variations, other than these, that have been observed seem to correlate more with the proton shell structure than the neutron shell structure. The yields seem also to correlate strongly with the variation of Z/A with Z.

Preliminary data from neutron yields produced by 32- to 18-Mev and 0- to 18-Mev protons indicate that the abrupt changes at Z = 20 and Z = 30 occur in the higher-energy interactions.

The yields have been measured by detecting the neutrons in a solution of $MnSO_4$ that surrounded the targets. To measure the differential yields (32-18 Mev and 18-0 Mev), we used the fact that C^{12} has a 20-Mev threshold for neutron production. Thus targets of such thickness as to reduce the proton energy from 32 to 18 Mev were backed by carbon and placed in a Faraday cup to measure the incident beam current. Alternatively, carbon targets to reduce the incident energy to 18 Mev were placed directly in front of other targets and the measured neutron production in carbon was subtracted from the combined yield.

BISMUTH FISSION CHAMBER

H. Wade Patterson

A large parallel-plate bismuth fission ionization chamber is now in operation. Forty-two parallel dural plates, each 15.5 cm in radius, have been coated with Bi, 1 mg/cm^2 thick. The plates are connected in series with a 1-megohm resistor between each plate. Twenty-five hundred volts applied to the middle plate provides the collection voltage, and the end plates are both grounded The signal developed by the passage of a fission fragment through the sensitive volume is brought out on the high-voltage lead and amplified by a factor of 10^5.

Approximately 20 grams of Bi are effective in sending fission fragments into the sensitive volume. The chamber has been roughly calibrated at the 184-inch synchrocyclotron by use of the 270-Mev neutron beam, and the background counting rate is now being determined.

NEUTRAL MESONS PRODUCED IN PROTON-PROTON COLLISIONS

Robert K. Squire

The characteristics of the production of neutral mesons in proton-proton collisions have been studied. The external beam of the cyclotron was allowed to bombard a liquid hydrogen target and the high-energy gamma rays arising from the creation and decay of π^0 mesons were detected with a counter telescope. Four independent experiments, consisting of three bombarding energies at one angle, and one energy at two angles, allowed a separation of the production contributions from the various angular-momentum states that can occur.

The excitation function is

$$\sigma \text{ (millibarns)} - 0.02\,\eta_0^2 + 0.57\,\eta_0^8 \left\{ \begin{array}{l} +\sqrt{(0.01\,\eta_0^2)^2 + (0.11\,\eta_0^6)^2 + (0.31\,\eta_0^8)^2} \\ -\sqrt{(0.01\,\eta_0^2)^2 + (0.11\,\eta_0^8)^2} \end{array} \right\},$$

where η_0 is the maximum mesond momentum in units of μc.
The angular distribution is

$$\frac{d\sigma}{d\Omega} = \frac{1}{4\pi} \left[0.02\,\eta_0^2 \left\{ \begin{array}{l} +\sqrt{(0.01\,\eta_0^2)^2 + (0.11\,\eta_0^6)^2 + (0.21\,\eta_0^8)^2} \\ -0.01\,\eta_0^2 \end{array} \right\} \right] + \frac{3}{4\pi}\left[0.57 \pm .11\right] \eta_0^8 \cos^2\theta.$$

It appears from this work that the production of π^0 mesons occurs principally in the P state, accompanied by two nucleons in a P state relative to one another, down to energies about 15 Mev above threshold, at which energy this production equals the production in S states.

This work has been published as UCRL-3137, September 13, 1955.

POSITIVE-PION TOTAL CROSS SECTIONS AT HIGH ENERGIES

Hoyt A. Bostick, Robert J. Cence, Selig N. Kaplan, and N. Fredrick Wikner

Efforts are being made to utilize the π^+ beam from the Bevatron target employed in the antiproton runs. The 32-ft rail that has been used in the π-p attenuation studies has been mounted inside the magnet ring in a region where positive particles are available with momenta extending up to approximately 3.5 Bev/c. The first attempts are involving measurements of π + p total cross section at about 1 Bev. The selection of this energy is accomplished by defining a momentum orbit with the use of part of the main Bevatron field, plus a sterring magnet placed in the re-entrant port of the west tangent tank.

In order to reject protons, which are present in the selected beam in large numbers, it is necessary to employ Cerenkov counters with indices of

of refraction so chosen that the protons will be below the Cerenkov threshold, whereas the pions will count with good efficiency. For the various momenta at which measurements are contemplated, this will involve the use of a liquid fluorocarbon with an index of refraction of 1.276, a liquid nitrogen Cerenkov counter with an index of refraction of 1.205, and a high-pressure CO_2 counter. This last type of device has been developed and tested by B. B. Kinsey and in recent work at 10 atmospheres CO_2 pressure it was possible to count pions at 2.8 Bev with 92% efficiency, whereas protons in the same momentum orbit were not registered. Variation of the pressure demonstrated a threshold for meson counting in agreement with that calculated.

This experiment is just beginning and there are no data to report at this time.

PAPER SUBMITTED

A paper titled "Terminal Observations on Antiprotons," by John M. Brabant, Bruce Cork, Nahmin Horwitz, Burton J. Moyer, Joseph J. Murray, Roger Wallace, and William A. Wenzel has been submitted to the Physical Review.

CLOUD CHAMBER STUDIES

Wilson M. Powell in Charge

PROTON-PROTON INTERACTIONS AT 5.3 Bev

William B. Fowler, George Maenchen, Wilson M. Powell, George Saphir, and Robert W. Wright

A 3-day Bevatron run was made with the 36-atmosphere hydrogen diffusion cloud chamber in the 5.3-Bev scattered proton beam described in the preceding quarterly report; 4500 pictures yielded 39 proton-proton interactions. Of these, six are elastic scatters, 14 are inelastic scatters with two charged outgoing prongs, 16 have four charged outgoing prongs, two have six charged outgoing prongs, and one event has two charged outgoing prongs and an associated Λ^0. Thirty-one of these events, which occured in a well-defined projected area in the cloud chamber, give 29.5 ± 5.5 mb for the proton-proton total cross section at 5.3 Bev. The standard error is nearly all from statistical uncertainty. Further runs are planned. A report on this work will be given at the Los Angeles meeting of the American Physical Society, December 1955.

MULTIPLE PION PRODUCTION IN n-p COLLISIONS AT THE BEVATRON

William B. Fowler, George Maenchen, Wilson M. Powell, George Saphir, and Robert W. Wright

A preliminary analysis has been completed of our data on multiple pion production in n-p collisions at Bevatron energies. The experiment was done by exposing the 36-atmosphere hydrogen diffusion cloud chamber to neutrons produced in the forward direction by collisions of 6.2-Bev protons with the 20° Cu target. A report (UCRL-3182) has been sent as a letter to the Editor of the Physical Review.

A 3-day Bevatron run gave 7000 pictures (not 70,000 as misprinted last quarter) and gave over 500 n-p events showing pion production. One event has seven outgoing charged prongs. Energy and momentum balance within the errors of measurement can be obtained for an incoming neutron kinetic energy of 4.7 Bev, so there is probably no neutral particle leaving the collision. The reaction is therefore believed to be

$$n + p \rightarrow p + p + \pi^{+} + \pi^{+} + \pi^{-} + \pi^{-} + \pi^{-} .$$

We are unable to rule out six-meson production, i.e. pp ++ --- 0 or pn +++ --- but both these possible reactions are considered less probable. Of the remaining events, 48 have five prongs and 473 have three prongs. The relative frequencies of occurence of events classified according to the number of visible prongs and the number of pions produced in the collision is given on the following page.

Observed type of event	3-prong			5-prong			7-prong		
Identified No. of Pions	1	1 or more	2 or more	3	3 or more	4 or more	5	5 or more	5 or more
No. of events	-	473	-	3	29	16	1	0	0

A preliminary analysis of the five-prong events indicates that 16 of these have one or more neutral outgoing particles, indicating the production of four or more pions. Identification of these events is based on (a) ionization and momentum measurements showing that two of the positive particles are pions (six cases), (b) lack of transverse momentum balance within the errors of measurement (seven cases) on both (a) and (b) (three cases). Production of three pions is indicated in three of the five-prong events that show transverse momentum balance. Because it is easier to establish the absence than the presence of momentum balance, 3:16 can only be considred within statistics as a lower limit to the ratio of three-pion to four-or-more-pion production in the five-prong events. The group of five-prong events listed as "three-or-more-pion production" consists of those events for which the presence or absence of one or more neutral outgoing particles has not been established. The grouping of the three-prong events into the "one-or-more-pion production" classification reflects the lack of analysis of this group. The multiplicity of pion production in this experiment is notably greater than the Brookhaven n-p results, where there were no five-prong events resulting from neutrons produced by 2.2-Bev protons on carbon.

π^--p INTERACTIONS AT 4.5 Bev

William B. Fowler, George Maenchen, Wilson M. Powell,
George Saphir, and Robert W. Wright

No additional runs were made during this quarter.

Analysis of the events previously obtained is continuing. In particular, a detailed analysis was made of three events involving the production and decay of heavy unstable particles. In two of these events only one decay was seen; one of these is a Λ^0, which is produced together with a positive particle that appears, from its momentum and relative ionization, to be a K meson. Another event contains two outgoing charged particles and a θ^0. The Q value of this θ is 222 ± 7 Mev. The third event is interpreted as the associated production of a θ^0 and a positive unstable particle, both of which decay before leaving the chamber. Estimates of the relative ionization of the positive particle and its proper time of flight of 1 to 2 x 10^{-10}sec favor its interpretation as a Σ^+ rather than a K^+. These three events will be described in more detail at the Los Angeles Meeting of the American Physical Society.

GENEVA CLOUD CHAMBER

Larry O. Oswald and Wilson M. Powell

A diffusion cloud chamber was built as a part of the American exhibit at the international "Atoms for Peace" conference in Geneva, Switzerland in August. The chamber was 4 ft square and 7 in. high with a track-sensitive depth of about 3-1/2 in.

The chamber was designed and built so that it was a self-contained unit measuring approximately 54 by 54 by 36 inches, needing only to be supplied with external power of 220 v, single-phase, 50-60-cycles.

The bottom of the chamber was a freezer plate that had Freon-22 circulated through it by a two-ton refrigerator unit. This kept the bottom of the chamber at -45°C, which was about optimum for the best racks.

The alcohol tray system, the chamber walls, and the top glass heating system were similar to those used in the 4-by-8-foot diffusion chamber.

A recycle alcohol system was used with excellent results. A pump supplied alcohol to an external adjustable-level reservoir which connected with the internal trays. The alcohol condensate was returned to the pump reservoir by an adjustable standpipe in the bottom of the chamber.

Illumination of the chamber was provided by five 300-watt sealed-unit incandescent lights. A mercury arc light could not be used because the ballast requires 60-cycle current and the chamber had to be operable on Geneva's 50-cycle current. The heat output of the incandescent lights was so great that it upset the thermal equilibrium of the chamber and thus had to be removed before it entered the chamber. This problem was finally solved by installing strips of heat-absorbing glass directly in front of the lights and then installing a water cell between the light box and the chamber. A few lengths of copper tubing in front of the refrigerator radiator served to cool the water, which was circulated by the same type pump as was used for the alcohol system.

This chamber was operated at Geneva for two weeks and for another two weeks at the New York showing of the American Geneva exhibit.

PHYSICS RESEARCH

Richman Group

NEGATIVE PROTON EXPERIMENT

Final calculations for this experiment indicate that a physica separation of π^- mesons and negative protons can be obtained by appropriate absorbers and bending magnets. The ratio of π^- to P^- will be reduced by a factor of 20 from the expected 5×10^4 to 1. This separation and other effects allow a larger exposure than would otherwise be feasible, giving an expected yield of more than 100 negative protons stopping in the nuclear emulsion stack.

The design was completed and the run originally scheduled for the first week in September. However, the run has been postponed until November.

MASS VALUES OF IDENTIFIED K MESONS*

James R. Peterson

The charged decay products of positive K mesons have been identified, and the masses of the primaries measured by the momentum-range method.[1] The K mesons were found in two nuclear emulsion stacks (meson energies of 170 and 114 Mev) after exposure behind the strong-focusing magnetic spectrometer at the Bevatron with incident proton energies of 5.7 and 6.2 Bev. Decay modes of mesons other than τ's were established by either (a) following the secondary to the end of its range (20 $K_{\mu 2}$'s and 20 $K_{\pi 2}$'s), (b) estimating the relative ionization by blob count at a considerable distance from the point of decay, or (c) measuring the relative ionization at the decay point. Reliable ratios of the frequencies of occurrence of various modes of decay have been obtained and are $K_{\mu 2}$; $K_{\pi 2}$; τ = 100: 56: 12 (τ includes alternate modes of decay), while the $K_{\mu 3}$ and K_{e3} each account for several percent of the total. Masses of the mesons are all consistent with that of the tau within a few electron masses. The data were obtained from about 200 events systematically selected from a total of some 1600 K mesons.

* Abstract for the Los Angles meeting of the American Physical Society, December 1955.

1 Birge, et al., Proceedings of the International Conference on Elementary Particles held in Pisa, Italy, in June 1955. To be published Il Nuovo Cimento.

ONE HUNDRED BEVATRON τ^+'s*

Roy Haddock

The decays of 100 τ^+'s found during systematic scanning of 3 emulsion stacks exposed to a magnetically separated K^+ beam at the Bevatron have been analyzed. The ranges of the π's were measured along the track. On the basis of Barkas's[1] range-energy relation the average Q was 75.20 ± 0.12 Mev.

The distributions in the π^- energy and the angle θ (angle between the relative momentum of the two π^+'s and the momentum of the π^-) have been compared by an χ^2 test with the theoretical relativistic distributions given by Fabri.[2] The cases for which a τ and a χ could be the same are excluded for spin less than 4. Of the remaining cases 1^+ is excluded and 0^-, 2^-, 3^+ can be fit satisfactorily.

The decay plane normals were computed and the distributions appeared to be isotropic.

* Abstract for the Los Angeles meeting of the American Physical Society, December 1955.

1 W. H. Barkas and D. M. Young, "Emulsion Tables. I. Heavy-Particle Functions," University of California Radiation Laboratory Report No. UCRL-2579 (Rev).

2 E. Fabri, Nuovo Cimento 11, 479 (1954).

Richman

RESEARCH WITH THE SPIRAL ORBIT SPECTROMETER

Ryokichi Sagane in Charge

Walter F. Dudziak, and James Vedder

A test with scattered electrons was made to determine (1) if magnetic saturation of pole tips was the only serious effect that distorted the early mu-electron data, thus giving the wrong Michel ρ-value, and (2) the possible variation of detection efficiency of our electron detector with changing positron energy over the measured positron-energy range in the mu-electron experiment. These measurements were made at the synchrotron. A 1/8-inch Pb converter was used to create positrons, and a cylindrical graphite target (2 inches od by 4 inches long) was used to scatter them. The graphite target was mounted on the axis of the spiral-orbit spectrometer. Intensity measurements were made of the scattered positrons over the positron energies in question. To test the first case two different magnetic geometries were used: (a) a saturation-free magnetic geometry (14.5-inch pole gap with no pole tips), and (b) the old mu-electron geometry. For each measurement the magnetic setting, which determines the energy of the detected positrons, was monitored with a nuclear fluxmeter. The nuclear fluxmeter probe was mounted on the magnetic pole of each geometry. The proper correction factor for this displacement of the probe from the median plane was obtained from earlier magnetic calibration measurements. Figure 7 summarizes the data on the effect of saturation on the detection efficiency of a spiral-orbit spectrometer. Because of the different focusing properties of the two magnetic geometries, the data obtained at the two lowest-energy points was used for normalization. When these corrections are applied to our old mu-electron measurements, we obtain good agreement (within statistical accuracy of the experiments) between the old mu-electron data and the mu-electron data obtained with the saturation-free magnetic geometry (14.5-inch gap, no pole tips). Following a suggestion (by Professor McMillan) that the positron distribution from the scattering target may not be symmetrically distributed about the median plane of the spectrometer, we used a Cu ring (2 inches thick and 30 inches id) to remove the positrons emitted into the solid angle defined by the median plane and the magnet pole farthest from the synchrotron. The positron intensity under these conditions was determined to be half of the total intensity.

The following procedure was used to determine the change of efficiency of our electron detector with positron energy. Plastic scintillator material of varying thickness was introduced into the focused positron beam before the detector. Measurements were made for each thickness t ($0 \leq t \leq 1$ inch) at positron energies of 34 Mev and 49 Mev. For quadruple coincidence (the method used during the mu-electron experiment), no variation of detection efficiency was observed. When a double-coincidence detection method was used, a 4% variation was observed for 4 32-Mev positrons when the thickness was changed from zero to one inch, and for the same thickness variation, a 1.5% difference was observed for 49-Mev positrons.

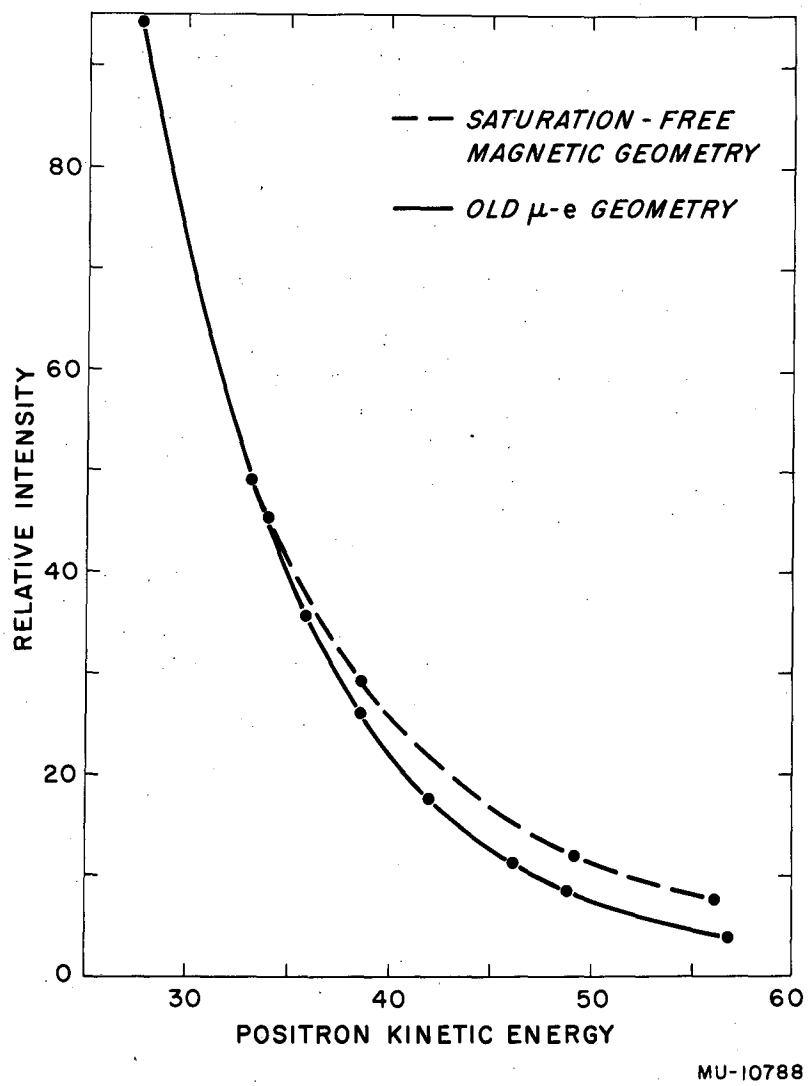

Fig. 7. Effect of saturation on the detection efficiency of a spiral-orbit spectrometer.

PHYSICS RESEARCH

Emilio Segrè in Charge

p-p POLARIZATION: MEASUREMENT OF THE LONGITUDINAL SPIN-ROTATION COEFFICIENT A*

John Baldwin, David Fischer, and James Simmons

Our most recent run on the 184-inch cyclotron has been concerned with a different and new kind of triple-scattering experiment. This experiment allows us to measure the change of the longitudinal component of the polarization when a proton is scattered by hydrogen. In order to do this it is necessary to deviate magnetically the polarized beam by an appreciable angle before scattering. The polarization vector rotates in a known fashion and acquires a longitudinal component, which is analyzed after scatterin in the usual way.

The special interest of this epxeriment lies in the fact that its results allow a choice between the various solutions of the phase-shift analysis of p-p scattering thus far obtained.

POLARIZATION IN PROTON-CARBON SCATTERING FROM 141 Mev TO 314 Mev

Karl Strauch

These measurements are an attempt to gain more information on the energy dependence of the polarization. They are reported in UCRL-3211.

ANTIPROTONS

Owen Chamberlain, Donald V. Keller, Emilio Segrè, Herbert M. Steiner, Clyde Wiegand, and Tom Ypsilantis

The main activity of the group has been concerned with the hunt for the antiproton at the Bevatron. The first successful experiments were done at the end of September (and are described and in summary in this report) in UCRL-3172.

The energy necessary to generate antiprotons in the laboratory has an absolute lower limit of $2\ mc^2 = 1.88$ Bev, but the mechanism of the collision and the conservation of momentum influence this lower limit, which becomes 5.6 Bev if the process is a nucleon-nucleon collision or 4.4 Bev if the process is a two-step one with the formation of a pion in a nulceon-nucleon collision followed by a pion-nucleon collision in which the nucleon-antinucleon pair is generated. (Energies in the laboratory system.)

When the Berkeley Bevatron was planned, the goal of 6 Bev was set with the hope that this energy would be sufficient to create antiprotons.

---

* Wolfenstein notation; see Phys. Rev. 96, 1654 (1954).

The methods of detection of the antiproton can make use of any of the seven characteristic properties. It seemed that charge, mass and stability might be the easiest to ascertain. Observation of annihilation would also be highly desirable, whereas generation of pairs, magnetic moment, and spin are at present very difficult to observe.

There are classical methods of measuring e and m that go back in their origin to J. J. Thomson. They entail the simultaneous measurement on the same particle of any two of the quantities momentum, velocity, or energy, which in turn can be obtained from the observation of electric or magnetic deflections, time of flight, range, scattering in photographic emulsion, etc. As for the charge, it is sufficient to measure its sign and its absolute value in a rough way only, because it is assumed that it is an integral multiple of the electronic charge.

After a detailed discussion it was decided that momentum p and velocity v constituted the most promising combination for ascertaining the mass. The first successful experiment was performed as follows: The momentum was measured by passing the particles generated by bombardment of a copper target with 6.2-Bev protons through two deflecting magnetic fields and two magnetic lenses. This ensemble let through only particles for which $p = 1.19$ Bev/c if their charge was equal to that of the electron, including sign. The velocity was measured by a time-of-flight measurement between two scintillation counters 40 feet apart. The pulse size in the scintillators showed that the particles were singly charged.

The chief difficulty in the experiment rests with the fact that the antiprotons are accompanied by many pions--44,000 pions per antiproton in the most favorable conditions. For this reason provision must be made for eliminating spurious background effects. One of the most important steps is the insertion in the beam of two Cerenkov counters: one that is activated by particles with $v/c = \beta > 0.79$ and one of a special type that is activated by particles with $0.75 < \beta < 0.78$. Pions with $p = 1.19$ Bev/c have $\beta = 0.99$, while antiprotons of the same p have $\beta = 0.78$ and their respective times of flight for an interval of 40 feet are 40×10^{-9} sec and 51×10^{-9} sec. Particles with β in the interval between 0.75 and 0.78 trigger the sweep of an oscilloscope in which the time of flight between two scintillation counters 40 feet apart is displayed. This time of flight appears as the distance between the two pips due to the traversal of the counters. From this time of flight the mass is determined with an accuracy of 10% for each particle. Up to now about 250 particles have been observed and the average mass is known to about 5%. It is 1840 ± 90 electron masses.

The functioning of the whole apparatus is checked by sending through it positive protons in a separate run. These are obtained from a subsidiary target and their orbits are selected in such a way that they have the same momentum as the antiproton.

The particles are observable after a time of flight of 10^{-7} sec, which rules out particles with a mean life much shorter than 10^{-8} sec, in particular the known hyperons. These measurements are thus in agreement with the charge, mass and stability mentioned above, and the identification of the

---

Segrè

new particle with the antiproton is a natural one, although not absolutely established.

Photographic experiments (by Owen Chamberlain, Warren W. Chupp, Gerson Goldhaber, Emilio Segrè, and Clyde Wiegand) were also performed jointly with a group at the University of Rome, Italy (E. Amaldi, G. Baroni, C. Castagnoli, C. Franzinetti, and A. Manfredini). The irradiations were performed with our analyzed beam, and half of the irradiated stacks were sent to Rome.

Intensive scanning in Berkeley and in Rome have resulted in the discovery thus far of one star due to an antiproton. This star was found in Rome and is to be described in UCRL-3224.

Certified antiprotons selected by our mass spectrograph were also delivered to another group in the laboratory that was concerned with the observation of terminal phenomena of antiprotons.

The observation of antiprotons at the Bevatron has opened up several new and promising research possibilities. We have initiated the panning of an experiment designed to detect antineutrons. It is expected that antiprotons will give rise to some antinuetrons by charge-exchange scattering, so an absorber (probably of copper) is to be placed in the existing beam of antiprotons, followed by a large thin scintillation counter and a massive scintillation counter. We hope to observe large pulses in the massive scintillation counter not accompanied by pulses in the thin scintillation counter. Such events would be interpreted as neutral particles entering the massive scintillation counter and annihilating there. A comparison of pulses due to the neutral particles with those due to antiprotons should enable us to say whether or not such events are due to antinuetrons. The massive scintillation counter is expected to be a massive sandwich of alternating sheets of lead and plastic scintillator. One section of the counter is under construction.

As an alternative to this counter we have under active study a scintillation counter containing large heavy NaI crystals and a counter using Cerenkov radiation from a high-density high-Z substance.

The apparatus that has been used successfully to discover the antiproton should also be used to search for other particles that may be produced in the Bevatron target. Negative particles in the mass interval from 900 to 3000 times the electron mass should be observable with the existing apparatus. An experiment to search for such particles is planned, to be carried out as the availability of Bevatron time permits.

As soon as possible explorations will be made to determine how the antiproton yield depends upon experimental conditions such as the selected momentum of the antiprotons. It is probable that more useful forms of antiproton beam may be found, particularly if we can obtain antiprotons of lower momentum.

Segrè

Investigation of the nuclear attenuation cross section for antiprotons is now under way. Preliminary work with a copper attenuator indicates that the absorption of antiprotons may be about twice as large as that for protons of the same energy (400 Mev). A lighter element such as beryllium or carbon will be studied soon, if available time permits. The current work will not give very precise cross-section values. Further work will be planned for the future.

Once it has been determined whether or not antiprotons are produced with momenta considerably lower than those used now, it may be possible to make emulsion exposures in which the whole range of the antiprotons is expended in emulsion. This method is an outgrowth of a suggestion by Edward J. Lofgren, and an exposure will be attempted as soon as Bevatron time permits.

DECAY MODES OF NEGATIVE K MESONS

Gösta Ekspong* and Gerson Goldhaber

By following along the tracks we have found four events that have been interpreted as decays in flight of negative k mesons. Two events were by their geometry suitable for a closer analysis of secondary particles.

The table gives the data for these low cases; the quantities are evaluated at the point of decay.

Case	Momentum of K	Mass of secondary	Momentum of secondary	Space angle of decay
1	205 ± 8 Mev/c	265 ± 30 m_e	170 ± 8.5 Mev/c	96.7° ± 0.1°
2	352 ± 25Mev/c	electron	37 ± 4 Mev/c	79.6° ± 0.1°

The nature of the secondary has been determined by blob-count and multiple-scattering measurements. For the second case its nature is certainly that of an electron, as shown by the low value of $p\beta$ observed (37 Mev/c) in conjunction with a blob-and-grain count that gave the result $g/g_0 = 1.03 \pm 0.04$. Where g_0 refers to the blob and grain density of π_--mesons of ~ 320 (?) Mev/c momentum used as calibrating particles. As there is no recoil or blob at the point of decay it is unlikely that either case represents a nuclear interaction. We have interpreted it as a case of a negative $K_{\beta 3}$. The energy of the electron in the rest system of the K-meson is also 37 ± 4 Mev.

In the first case the mass of the secondary has been determined by a comparison with a particle known to be a π meson. The momentum given in the table has been computed from the observed $p\beta$ with the assumption that the secondary is a π meson. (If it were assumed to be a μ meson the momentum would be p = 154 Mev/c). For the observed angle of emission

* On leave of absence from the University of Uppsala.

Segrè

and the observed K-meson velocity the expected momentum of the secondary is 172 Mev/c for $K_{\pi 2}$, whereas for $K_{\mu 2}$ it is 202 Mev/c, where the mass of the negative K is assumed to be 965 m_e. There the $K_{\mu 2}$ scheme can be definitely ruled out. The measured mass of the secondary (265 m_e) and the close fit to the expected momentum of the $K_{\pi 2}$ scheme make it very likely that this case represents a negative $K^- \rightarrow \pi^- + \pi^0$. If we make a transformation of the π-meson momentum to the rest system of the K mesons we find its momentum to be $p^* = 202 \pm 12$ Mev/c, where the error includes the uncertainty in the velocity of the K meson. From this and an assumed decay scheme $K^- \rightarrow \pi^- + \pi^0$ the mass of the negative K is found to be 957 ± 40 m_e.

INTERACTIONS IN FLIGHT OF K⁻MESONS

Edwin L. Iloff, Gerson Goldhaber, and Joseph E. Lannutti

The analysis has been completed on the K^- interactions found in 4.8 meters of K^- meson track. These have been followed in a stack of Ilford G.5 nuclear emulsions, which was exposed to the K^-- meson beam at the Bevatron. Nineteen interactions of K mesons in flight have been identified. In addition there are also four possible interactions in flight, which have not been completely analyzed as yet. Not including the questionable events, this gives a mean free path of K^- mesons in emulsion of 25^{+7}_{-6} cm.

Table I gives the prong distribution of the stars.

Table I

No. of prong	No. of stars
0	3 + (1)?
1	3 + (2)?
2	3 + (1)?
3	4
4	3
5	2
6	0
7	1

4 + (2)? of the interactions emit charged π mesons. Two have charged hyperons emerging, one of which stops and is identified as a Σ^+ by its decay. The other hyperon decays in flight.

This work was done in cooperation with Sulamith Goldhaber.

ACCELERATOR OPERATION AND DEVELOPMENT

BEVATRON

Edward J. Lofgren in Charge

Further progress in the Bevatron program is the subject of a separate report by Edward J. Lofgren and Walter D. Hartsough, "Bevatron Operation and Development. VI," UCRL-3212. November 18, 1955

184-INCH CYCLOTRON

Robert L. Thornton in Charge

MODIFICATION

Richard Burleigh

The shutdown started as scheduled on September 12 and the following work has been accomplished to date:

1. Removal of shielding, radiofrequency system, probes ion source, pole tips, dee tank and upper coil tank.
2. Rework of dee tank.
3. Installation of meson cave foundation.
4. Rework of magnet yoke.
5. Rework of upper vacuum-barrier disc.
6. Drilling of lower pole-disc stack.
7. Installation of new upper main-coil strongbacks.
8. Strengthening of upper coil brackets.
9. Rework of upper main-coil tank.
10. Installation of wire-ways in floor.
11. Relocation of mechanical vacuum pumps outside building.

Work is in progress on the following items:

1. Miscellaneous plumbing.
2. New control room.
3. Miscellaneous electrical work.
4. Drilling of upper pole-disc stack.
5. Replacement of upper main-coil maple insulation with bakelite.
6. Installation of auxiliary coil clamp bank drains.
7. Nitriding of new vibrating blades.
8. Experimental movable panels.
9. Design of meson cave slot shielding.
10. Preliminary design of deflector system.
11. Design of wire loop system for median-plane determination.
12. Drilling of poles for auxiliary coil supports.

Thornton

60-INCH CYCLOTRON

Joseph G. Hamilton in Charge

OPERATION

G. Bernard Rossi

The 60-inch cyclotron was operated during the current quarter for 1098.6 hours at an efficiency of 87.0%. The frequency shifter described in the preceding report was operated twice to permit the acceleration of oxygen and nitrogen ions. Little difficulty was experienced in lowering the frequency to 10.7 megacycles or in returning to 12.1 Mc.

A number of ion-source variations were tried while operating with heavy ions aimed at the development of a more prolific source of higher-order ions. None proved much better than the standard water-cooled capillary type now in use. More experiments are planned along this line for the near future.

The frequency shifter was also used to lower the beam energy from 12.1 Mev per nucleon to 11.9 Mev. Work with alpha particles at this lower energy (47.6 Mev) produced 100 μa of deflected beam. This value was reproducible without much difficulty and served to perform continuous bombardments of 1 to 16 hours. One hundred kilowatts of input oscillator power was necessary to obtain the dee voltages needed for this type of performance. Little difficulty was experienced with rf voltage breakdowns except in the region of the exit strip-deflector area. Spot heating of the tungsten exit strip caused deflector voltage discharges which eroded through the upper tank liner. This liner area had been designed for easy replacement, which was done in three hours of shutdown time, excluding subsequent pumping and baking. Readjustment of the source - dee parameters has arrested this condition.

A study is being made of all the water-cooling lines in the cyclotron by means of thermistors introduced into each line. The average rise in temperature above that of the cooling-water reservoir was found to be 4-1/2°C; the range of temperature rise was from 2°C to 21°C; the equilibrating time was ten minutes and the decay time about five minutes. The lines subject to the largest rise are the inner conductors of the newly installed frequency shifters. The design flow rate through these lines (2.5 gal per minute) still prevails, and a recent inspection of the rf connections in the system revealed no excessive local heating points. These temperature rises when translated into power loss at the present flow rate account for from 10 to 15 kilowatts loss in oscillator power. This approach was dictated by an apparent increase in power used for beam extraction since the installation of the frequency shifter. Efforts are being made to understand this power loss so that corrections can be applied.

Summary of operations as prepared by W. B. Jones for this quarter:

Alpha bombardments	618.3 hr
Deuteron bombardments	160.0 hr
Proton bombardments	160.2 hr
Carbon bombardments	10.8 hr
Nitrogen bombardments	49.5 hr
Oxygen bombardments	57.7 hr
Experimental bombardments	42.1 hr
Operational total	1098.6 hr
Outage time	166.9 hr
Available time	1265.5 hr
Shutdown	925.5 hr
Holiday	16.0 hr
	2207.0 hr
Daylight Saving Time	1.0 hr

Hamilton

LINEAR ACCELERATOR

James D. Gow in Charge

The linear accelerator operated a total of 654 hours of research bombardments during this quarter. A scheduled shutdown of 290 crew-hours was made to permit the installation of new oscillator positions and control cabinets. Owing to lack of manpower, the final connections from the new oscillators to the resonator were not made. A short shutdown will be made later to complete this work.

The general program of Nuclear Scattering and Spectroscopy continued as in the past. Experiments included investigations of energy levels in B^9, total neutron yields for various targets at 32 Mev proton energy scattering of protons from lithium, and excitation of the 15-Mev γ level in carbon. In the course of the scattering experiments, the energy spread of the linear accelerator beam was measured by measuring the energy distribution of elastically scattered protons from various targets. The beam appears to have an energy spread (full width at half maximum) of about 100 kev. Shifts in the mean energy were found to occur. In extreme cases the shifts amounted to as much as 700 kev. A run was undertaken to determine the cause of these shifts. The major shifts appeared to be associated with temperature changes of the cavity. It was also found that the energy could be shifted as much as 250 kev by a 0.015-inch motion of the end tuning drift tube. Shifts of the order of 100 kev were produced by variation in the plate voltage of the main oscillator over the noraml operating range.

A method of monitoring the mean energy continuously by use of a time-of-flight technique is under investigation. If the method proves practical, it will be installed.

SYNCHROTRON

Edwin M. McMillan in Charge

RESEARCH PROGRAM

Robert W. Kenney

During the last quarter, experimenters have required peak photon energies from the synchrotron in the range from 100 Mev to 340 Mev, with spread-out beam. The machine has run extremely well at all energies.

Larry Higgins has been measuring the energy dependence of the cross section for Compton effect on protons by detecting the recoil photons at 90° from a liquid hydrogen target placed in the synchrotron photon beam. The peak photon energy was held below meson-production threshold in order to avoid contamination of the observed effect by neutral-pion decay photons. A four-crystal telescope was found necessary in order to discriminate against neutron background. Data have been taken during two runs and the results will be available soon.

William Imhof, Victor Perez-Mendez, and Edward Knapp have gathered additional statistics on the cross section for the photoproduction of π^+ mesons at 135° (lab) as a function of Z in an effort to determine the π^+ mean free path in nuclear matter as a function of pion energy. The data are compatible with a value $\lambda = 2\ r_0$, independent of energy. Additional work will be done at pion energies below 30 Mev.

Ryokichi Sagane, Walter Dudziak, and James Vedder have observed a spectrum of scattered electrons with the large spiral-orbit spectrometer in order to calibrate a particular spectrometer geometry that was used in the μ-electron decay experiments. This calibration was then employed in comparing the old ρ data with more recent experiments.

The same experimenters have begun to look at the π^-/π^+ ratio from deuterium at 90° (lab) and at pion energies of 30 Mev, 20 Mev, and 12 Mev, using the large spiral-orbit spectrometer. Data are currently being taken.

John Anderson and Robert Kenney have studied the Z dependence of the cross section for π^0 photoproduction at 135° (lab) in an effort to determine the pion mean free path in nuclear matter without the complications due to Coulomb corrections which arise in the π^+ photoproduction. The data, for high-energy π^0, are compatible with a value $\lambda = 2\ r_0$ in nuclei heavier than Al. The π^0 yield for nuclei lighter than C is proportional to A, within statistics of 3%. The region below Al will soon be looked at in more detail with apparatus that will define the π^0 energy more closely than does the present equipment.

John Dudley, Fred Inman, and Robert Kenney have been attempting to observe polarized bremsstrahlung. An account of this work is contained in the quarterly report of the Barkas group.

OPERATION

Rudin M. Johnson

The synchrotron has been operating entirely for physics research experiments during the period of August, September, and October. Owl shifts stopped after the start of the fall semester because the summer crew of graduate students went back on half-time work.

The beam intensity at full energy was increased two- to threefold, so that the intensity was approximately one-half the previous maximum. There is no apparent reason for this increase, although the injector gun filament was changed from 0.010-inch to 0.012-inch-diameter tungsten wire at this time. This increase in filament wire size has increased the life of injectors from approximately 35 hours to 250 hours or better.

During the first part of August and October, the magnet was run at approximately half voltage with beam energies below the meson threshold of 140 Mev. At these energies the beam pulse was 200 to 400 μsec long and its intensity the same as full-energy beams.

A vacuum leak developed in the vacuum doughnut, apparently through the rubber boot at the high-current end of the resonator quartz. This leak was repaired and the synchrotron put back into operation by injecting glyptal varnish around the boot area.

The ceramic vacuum sections to be used with the linear accelerator injector have been machined and vacuum-tested. These sections are ready for testing with the electron linear accelerator.

The 2-Mev accelerator has not been in operation because of failure of the magnetron high-power microwave oscillator. The spare magnetron developed a short between cathode and filament. The manufacturer cannot provide a replacement at the necessary frequency and will not rework our present magnetrons. A tunable klystron has been ordered, which will be operated as a self-excited oscillator. Delivery is expected December 1, 1955.

The synchrotron linac Model II is about 50% complete. The mechanical parts are essentially finished and are in various stages of assembly in the electron installation shops and Building 68. The accelerator dolly is nearly complete. The vacuum system is working. The pulse transformers and pulse lines are nearly completed. The main power supply and controls are just beginning construction. The linac should be ready for test runs in the latter part of December.

The mechanical and electrical design for the synchrotron magnet voltage regulator is under way. The regulator and rf link have been designed and are under construction. Installation of the complete unit is tentatively scheduled for the latter part of December.

McMillan

Information Division
12-15-55 jm