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PHYSICS DIVISION QUARTERLY REPORT

February, March, April 1956

May 22, 1956

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PHYSICS DIVISION QUARTERLY REPORT

February, March, April 1956

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February, March, April 1956

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GENERAL PHYSICS RESEARCH

PHYSICS RESEARCH

Luis W. Alvarez in charge

LIQUID HYDROGEN BUBBLE CHAMBERS

Luis W. Alvarez, James Donald Gow, and group

10-Inch Chamber

During this quarter two runs were made with the 10-inch chamber. The first of these was made in a π^- beam variable from 0.7 Bev/c to 1.5 Bev/c, and was considered strictly as a test run. All the cures that had been attempted for reducing the temperature gradient in the chamber were successful to some degree. The fast-recompression system proved to reduce the gradient to a point where minimum-ionizing particles could be detected anywhere in the chamber. During this run, about 3000 pictures were taken for subsequent analysis. The second run was made in a beam from the new northwest target facility. This beam was designed to provide stopping K^- mesons, separated from pions, in the chamber. During this run difficulty was experienced with electron contamination of the beam. Also the flash lamps used for photography failed after about 1000 cycles. A target change will be made in an attempt to reduce the electron background. The light insulation will be improved and a run will be made early in May with the same setup.

Plans are being made to put an increased-diameter chamber into the magnet, possibly as large as 15 inches. This chamber will use one-window illumination and will be essentially a model of the 72-inch chamber.

72-Inch Chamber

The low-hydrogen-consumption operation that has been attained with the fast vapor-recompression system on the 10-inch chamber has led to the design of a similar system for the 72-inch chamber. Although this method of pressure control requires about twice as much refrigeration as the theoretical liquid-expansion system, the resulting simplicity, elimination of rapidly moving low-temperature pistons and driving machinery, and the savings on the liquid-expansion development will result in substantial savings on the over-all chamber costs.

Adoption of this method has permitted immediate freezing of the general design of the compressor-refrigerator components. The chamber and expansion system are now in the detailed design stage.

The magnet design has been released for fabrication, the copper and steel are on order. The copper for fabrication of the chamber is on order and negotiations for fabrication of the top window are under way. The glass test program at the Boulder Laboratory of the National Bureau of Standards has been completed. Present schedules call for delivery of most of the major components for the 72-inch chamber around January of 1957.

The illumination system for the 72-inch chamber requires some experimental work, which is now being done. A full-scale wood model of the chamber has been made for optical studies.

Photographic Analysis

The analysis group has begun processing film from the various 10-inch runs. The precision digitized reader is nearing completion and a computer program to convert punched-card track-coordinate data into particle momentum has been completed. This program has been test run on an IBM 650 computer. It includes corrections for nonuniformity of magnetic field and optical distortion over the chamber volume.

Investigations of the proposals by various commercial suppliers for providing semiautomatic track-following readers are continuing.

LIFETIMES OF τ, $K_{\pi 2}$, and $K_{\mu 2}$ MESONS

Luis W. Alvarez, Frank S. Crawford, Jr., Myron L. Good, and M. Lynn Stevenson

Sufficient data have been recorded on film in the form of oscilloscope sweeps to determine the mean lives of the τ, $K_{\pi 2}$, and $K_{\mu 2}$ mesons, each to about 3% statistical accuracy. Data reduction is being done on a semi-automatic scanner that punches the data onto IBM cards. The results of this experiment are forthcoming.

SEARCH FOR A POSSIBLE CASCADE GAMMA RAY IN $\tau \rightarrow \theta$ DECAY

Luis W. Alvarez, Frank S. Crawford, Jr., Myron L. Good, and M. Lynn Stevenson

An experiment involving the electronic detection of the decay fragments of heavy mesons has shown no evidence for the existence of the process $\tau \rightarrow \theta + \gamma$ where the γ-ray energy is more than 300 kev. Nothing can be said about the existence of γ rays of energy less than 300 kev.

PHYSICS RESEARCH

Walter H. Barkas in charge

DEVELOPMENT OF NEGATIVE K-MESON BEAM

Walter H. Barkas, Walter F. Dudziak, Peter C. Giles,
Harry H. Heckman, Fred W. Inman,
and Norris A. Nickols

A major effort of this quarter has been the preparation for extracting a useful K^- beam from the Bevatron. Earlier work (W. H. Barkas, Note on the Negative K Particles Produced at 0°, UCRL-3269, Jan. 1956) had shown that negative K mesons of ~430 Mev/c emitted in the forward direction from a copper target could be caused to emerge radially from the Bevatron after being momentum-analyzed by the Bevatron field. The K^-/pion ratio at the point of emergence was about 1/2500.

Careful analog computer work has now been carried out to define the intervals of angle and momentum in which the particles are expected to lie. In cooperation with Rosenfeld and Tripp of the bubble chamber group, the effect of a 4-inch strong-focusing lens at the exit port has been evaluated and a stack of emulsion was exposed at the focus of the lens some 10 feet from the point where the mesons emerge from the Bevatron. The flux of K^- mesons found at this point amounted to about 3/cm^2/min. A more precise figure, as well as the K/π ratio, is being determined.

A second part of the beam system consists of an energy degrader at the exit of the strong-focusing lens and a second bending magnet. This is designed to give a complete separation of the K mesons from the pions by bending the differentially degraded particles through 180°. Pole pieces giving both vertical and horizontal focusing have been built for the large Sagane magnet. Field measurements have been made and particle trajectories plotted with our analog computer. Bundles of orbits of up to 300 Mev/c can be focused with the magnet. The expected gains using this beam are great enough so that a determined effort is being made to obtain Bevatron time to test and use it.

INTERACTIONS OF ANTIPROTONS IN NUCLEAR EMULSION

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

In a 2-by-3-by-6-inch emulsion stack exposed to the 700-Mev/c negative particle beam, seven particles satisfying the entrance criteria for antiprotons were found. Four particles of about 14 cm residual range annihilated after coming to rest, giving rise to from 2 to 9 visible star prongs. The average number of pions per annihilation in these events was 1.5. One event showed no visible prongs upon coming to rest, one annihilated in flight, and one left the stack after 7 cm path length.

The maximum observable energy in the annihilations at rest was ~900 Mev. This annihilation in flight has been interpreted as a p^- collision with a light nucleus, with good evidence that one of the prongs is a K meson.

Upon assumption of reaction

$$p^- + O_8^{16} \rightarrow \begin{Bmatrix} \Sigma^- \\ \text{or} \\ p \end{Bmatrix} + K + \begin{Bmatrix} \pi^+ \\ \text{or} \\ \pi^- \end{Bmatrix} + d + B_5^{11} + \begin{Bmatrix} n \\ \text{or} \\ \Sigma^0 \text{ or } \Lambda^0 \end{Bmatrix} ,$$

it is possible to balance energy and momentum when the total energy release is 2 $M_p c$. It is not possible in this event to infer whether the annihilation took place through the production of a pair of K or of π mesons.

RANGE-MOMENTUM RELATION FOR EMULSION

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

Work is continuing on the low-velocity portion of this curve. The high-velocity work was largely completed. Earlier low-velocity work consisted of measuring the ranges of protons, deuterons, tritons, He^3, and He^4 particles that had been magnetically analyzed and entered an emulsion pellicle through the surface. Rather elaborate precautions were taken to keep the density of the surface layer uniform and known.

The present work consists of measuring protons recoiling from neutrons of known energy (t, d reaction) in the body of a stack of emulsion, and of measuring ranges of alpha particles entering through the surface as a function of their dip angle and the state of desiccation of the emulsion.

THEORETICAL GROUP

David L. Judd

Equations describing the photoproduction of pion pairs by gamma rays have been derived by use of the Chew-Low-Wick method. Some predictions of these formulae have been compared with the experimental results on this process obtained at Stanford. There is qualitative agreement with the observation that one meson tends to come out in a P-wave resonance with the nucleon, leaving little kinetic energy to the second meson. (Saul Barshay)

Attention is being turned to a model of the pion-nucleon P- and S-wave interactions formulated along the lines of the Lee model. This model can be renormalized without the aid of perturbation theory and can be solved exactly. Of special interest is the process involving the production of 2 S-wave mesons by a P-wave meson; it is hoped that some light may be shed on the relationship between the renormalized P- and S- wave coupling constants. (Saul Barshay)

An attempt is being made to understand the τ and θ decays of K-mesons without using the parity degeneracy formalism. A weakly coupled scalar π^0 is not in contradiction with experiment and can explain the lifetimes and branching ratios of charged and neutral K's. This scheme makes K^+ and K^0 have opposite parities, so that charge symmetry no longer obtains in strong virtual processes involving K mesons. Charge symmetry can be preserved by assuming charged mesons (or even nucleons) of opposite parity also. (Sidney Bludman and Malvin Ruderman)

The phase-shift analysis of the 310-Mev p-p polarization experiments has been concluded. In the completed work the phase shifts through H waves (14 phase shifts) were included. Five solutions consistent with the data have been found. In these solutions the $^1S_0$ phase shift is negative, indicating a hard core in the singlet central potential (in even angular momentum states if the potential is parity-dependent). The $^3P_0$ phase shift is negative in the acceptable solutions, contrary to the previous theoretical expectations. It is now believed that the ^3P potential may be strong enough to reverse the sign of this phase shift. This possibility is the basis of an extensive investigation at another laboratory. A detailed analysis of the phase shifts by Gammel at Los Alamos has led to the conclusion that a satisfactory potential cannot be obtained by using only central and tensor forces unless the potentials are strong enough to produce resonances. The effect of including an $L \cdot S$ force is being investigated here. An attempt to obtain phase shifts at other energies by an extrapolation technique and to obtain the n-p phase shifts at 310 Mev is planned. (Henry P. Stapp)

An analysis of the physical applicability of wave functions and energy levels computed for nucleons moving in a spheroidal potential with spin-orbit coupling is now being made. Consideration is also being given to a recalculation of wave functions under the assumption that the energy-level diagram to be fitted to the empirical filling order of nucleons in nuclei is that of $\langle T_i + \frac{1}{2} V_i \rangle$ and not the energies, $\langle T_i + V_i \rangle$, of the single-particle equation solved in such single-particle model calculations. (Marvin Rich)

A review article on statistical models is being prepared for the Annual Review of Nuclear Science. (Joseph V. Lepore)

By use of second-order perturbation theory, expressions have been obtained for cross sections for scattering of K^+ mesons from protons and associated production of strange particles. The calculation has been done by assuming spin zero bosons and spin one-half fermions. The pions have been taken to be coupled directly in all cases; up to and including derivative couplings were considered for the K^- mesons. The possibilities of both parities of the baryons (and therefore of the K's) relative to the nucleons were considered. The cross sections are now being numerically computed. (Richard Spitzer)

Dispersion relations for finite momentum-transfer pion-nucleon scattering have been derived and analyzed in terms of states of different orbital angular momenta and spin dependence. For values of the momentum transfer appreciably greater than μc (where μ is the meson mass) the analysis is not strictly justified; the degree of accuracy of the resulting equations is not known at present. Approximate equations for low-energy S- and P- wave scattering are given. (Richard H. Capps)

The 300-Mev proton-proton scattering phase shifts obtained by Stapp and Ypsilantis from the analysis of the p-p scattering experiments at Berkeley are being analyzed in terms of a potential well model. Scattering in the S and P states has been examined in most detail. While suitable fits to the high-energy data in terms of a potential well are possible, satisfactory energy-independent solutions have not as yet been determined. From a superficial examination of the triplet scattering phase shifts, it is suggested that a simple $L \cdot S$ potential may account for a large amount of the spin-dependent scattering, and a more detailed examination of this is to be undertaken. It was found necessary in the course of the work to spend a considerable amount of effort to devise suitable routines for differential analyzer operations in order to obtain sufficient accuracy. (Warren Heckrotte and Al Garren)

A study of the elastic scattering and polarization of high-energy deuterons by nuclei is being made. The measured large-angle scattering and polarization is substantially larger than that calculated by the usual impulse approximation. A physical argument suggests that this discrepancy may be explained by multiple-scattering corrections. Calculations along this line are being made. (Warren Heckrotte)

The Lepore-Neuman phase-space integrals for two, three, and four particles have been evaluated numerically. By use of these numerical values, an attempt has been made to adjust the cutoff parameters of the theory so as to fit the rather sketchy data on pion production in p-p collisions, and the multiplicities observed in the antiproton annihilation. It appears that both production and annihilation data can be fit fairly well with the same parameters, but a smaller parameter, corresponding to a larger interaction volume, may be required for the annihilation. A better comparison will be possible when more data are available. (Dan H. Holland)

The theory of K^+ scattering on nucleons has been investigated. Comparison with experiment is at present impossible, for the data are contradictory. However, if, following L. S. Osborne, one assumes that the low-energy scattering is s-wave attractive, then it follows that there is a hyperon that has spin 1/2 and the parity (relative to the nucleon) of the K. This particular case has been calculated in the Chew-Low formalism, which is trivially set up from the dispersion relation. It is amusing, and perhaps will someday be useful, that the effect of pion-containing intermediate states on the K^+ scattering enters solely through the K^- nucleon cross section (principally absorption). It might be noted that regardless of the spin-parity assignment of hyperons and K mesons (but with the assumption that it is unique), lowest-order perturbation theory implies that K^+-neutron scattering cannot be peaked forwards; for K^+ protons the existence of both Σ^0 and Λ^0 precludes such a statement. (Charles J. Goebel)

Computations are under way to investigate the effect of energy-dependent forces in S-state nucleon-nucleon scattering by observing the change in size of the $^1S_0$ core due to the inclusion of the 310-Mev polarization phase shift. (Robert B. Raphael)

A general survey of design for high-energy alternating-gradient accelerators has been initiated. The program calls for the use of fast computers in investigating betatron oscillation frequencies and oscillation amplitudes in a wide variety of magnet configurations and field-gradient requirements. These include the following basic types:

(a) combined bending and focusing,

(b) separated function (no focusing in bending sectors, and vice versa),

(c) combined function (some bending in focusing sectors).

It is hoped that such a study will prove a useful first step in obtaining the most efficient design. (Robert B. Raphael, Dan H. Holland, and David L. Judd)

The effects of nonnormal entrance of particles into accelerating gaps in a variety of accelerators is under study. (Stephen Gasiorowicz and David L. Judd)

Some work was done on the nucleon-antinucleon forces, in particular on whether the terms which for the nucleon-nucleon force lead to a repulsive core could lead to a correspondingly strong attraction. The result was negative. Some thought has been given to the θ - τ dilemma. In particular one may accept the nonconservation of parity in a "weak" reaction by observing that although formally a lack of such conservation could in principle allow one to decide between a "right-handed" and a "left-handed" world, the presence of the uncertainty principle would make such a decision ambiguous, thus still preserving the weaker requirement that no experiment should allow one to distinguish between the two cases. (Stephen Gasiorowicz)

Members of the computing and mathematics section of the theoretical group are primarily concerned with the use of fast electronic digital computing machines. They are under the direction of James Baker and have made the following progress during the last quarter:

A program for processing data from the bubble chamber is being completed. This program accepts, as raw data, sets of microscope measurements of (x, y) coordinates along a track from two pictures of the track. From these coordinates, and from measurements of fiducial marks on the films, the true (x, y, z) coordinates of the track in the chamber are computed. The track is then rotated so that a line passing through its end points is parallel to one of the axes; a polynomial of degree two is fitted to the track in the sense of least squares, a measure of the goodness of fit is calculated, and the curvature of the track is computed. The magnetic field in the neighborhood of the track is found, and, finally, the momentum of the particle is computed. This momentum together with the true coordinates of the track are produced as output. (Robert Johnston for the Bubble Chamber Group)

A revised and enlarged edition of the Beverly Hill Willis report on High-Energy Particle Data is under preparation. Calculations have been made for new graphs which will aid in the transformation of momentum and energy to the center-of-mass system for the following cases: π mesons, K mesons, protons, electrons, and photons, all incident on protons. These data, along with new graphs for τ mesons, and the Λ and Σ hyperons, will be included in the revised edition. This work is being done for the Information Division at the suggestion of Dr. Luis Alvarez. (Charles Stableford)

A code has been developed in connection with the cancer research program being carried on at the 184-inch cyclotron. Its purpose is to determine the distribution of the beam intensity at the pituitary for various positions in which the patient may be placed. (Charles Stableford for Dr. Cornelius Tobias of the Medical Physics Group)

A program to compute the theoretical efficiency of detection of K-meson decay in the reaction $K^+ \rightarrow \pi^+ + \pi^0$ was devised at the request of Lynn Stevenson for counter arrangements used by him and his associates in Bevatron experiments. (Kent Curtis)

A set of tables listing the angles and energies of the scattered particles in both the laboratory and center-of-mass systems for the elastic scattering of K mesons by protons for meson energies in the laboratory system (proton at rest) ranging from 10 Mev to 6 Bev was prepared at the request of Lynn Stevenson. These tables have been published as UCRL-3274. (Kent Curtis)

A program to aid in the analysis of complex nuclear spectra by listing all sums and differences of pairs of lines in a set of observed lines which are equal within an assigned tolerance was prepared for Arnold Fritsch of the Nuclear Chemistry Group and has been used by him and Jack Hollander in the analysis of several spectra. (Kent Curtis)

A program has been completed for the reduction of data from observations of the number of prompt neutrons emitted in spontaneous fission. The observations are pulse heights in neutron counters surrounding the fissioning material. The observed distribution of pulse heights is corrected for efficiency of the neutron counters and resolution of the heights to find the true distribution of the number of prompt neutrons emitted. (Alice McMullen for Robert Pyle and Donald Hicks of C. M. Van Atta's Group)

A code for the computation of all the eigenvalues and eigenvectors of an n x n matrix with n distinct eigenvalues has been completed. This code employs a method due to Lanczos and Hestenes; it is good for $n \leq 15$. (Harold Hanerfeld for Marvin Rich of the Theoretical Group)

A program has been prepared which fits K points ($1 \leq K \leq 20$) with a polynomial of degree n, ($1 \leq n \leq 19$) in the sense of least squares. The program computes the n + 1 coefficients of the polynomial and the function values of the polynomial at the input points. (Keith Johnson for the Bubble Chamber Group)

A program to calculate the placement of shims to adjust the magnetic field of the 184-inch cyclotron has been prepared, and a paper has been presented on it at the Washington meeting of the American Physical Society. (James Baker with Warren Stubbins of the 184-Inch Cyclotron Group)

Work is continuing in the numerical aspects of alpha decay from deformed nuclei of very large nuclear moments of inertia. The wave-function distribution at the nucleus is obtained from an inward integration from large distances, where experimental data and the Coulomb wave equation give the necessary starting values. Since it is not accurately known for the elements under study, several values of the quadrupole moment are being used to give a range of values within the known limits. (Eldon Hansen with John Rasmussen of the Nuclear Chemistry Group)

PHYSICS RESEARCH

Edward J. Lofgren in charge

PROTON-PROTON ELASTIC SCATTERING CROSS SECTION

Charles W. Causey, Jr. Bruce Cork,
and William A. Wenzel

Insertion of a counter through the north outside air lock of the west tangent tank of the Bevatron permitted measurement of the p-p elastic scattering cross section at small angles. The forward counter was automatically rotated through 90° into position during the acceleration cycle. The 1.5-by-0.5-by-1/16-inch polyethylene target in the south end of the straight section was oriented in such a way that protons recoiling at large angles would penetrate a minimum of target material. The target was dropped into the center of the aperture on two nylon threads tied to an arm operated by a rotary solenoid. The cross section was measured by a threefold coincidence between the front counter and a remotely controlled two-counter telescope outside a thin window on the inside of the straight section. This was sensitive to recoil protons formed with energies as low as 30 Mev. The cross section has been measured at laboratory angles down to 2° at 6.2 Bev, 3° at 4.4 Bev, and 5° at 2.24 Bev. Absolute cross sections are obtained by normalizing to the internal circulating beam.

ANTIPROTON SELECTING SYSTEM AND TARGET

Bruce Cork, Glen Lambertson, Oreste Piccioni,
and William A. Wenzel

The system described in the preceding Quarterly Report (UCRL-3326) is being developed. A 6-inch-long Be target is located at the 5° position near the Bevatron west straight section. Antiprotons produced in the forward direction are deflected out through a thin window and focused by 4-inch-diameter strong-focusing quadrupole magnets. A time-of-flight counter system is being developed to help identify the antiprotons.

The focal properties of the Bevatron magnetic field and of the quadrupoles have been calculated, and the quadrupoles have been assembled to have the desired properties. The magnetic fields and bent-wire orbits have been measured, and further calculations are being made to determine the orbits.

The scintillation counters using 14-stage 6810 photomultipliers are being checked to determine their properties. The new coincidence circuits are being checked. A liquid nitrogen Cerenkov counter to help reject mesons is being built.

A liquid hydrogen target that is 8 inches in diameter and 60 inches long is being assembled. This target is enclosed in a vacuum jacket that is cooled with liquid nitrogen.

The initial experiment will be to determine the orbits of negative particles from the Be target for several momenta, to check the focal properties of the magnets, and to measure the flux of negative particles at various points along the orbits.

The ultimate aim of the experiment is to measure, as a function of antiproton energy, the total absorption cross section in hydrogen and to try to detect antineutrons produced by charge-exchange scattering of antiprotons. For this latter part of the experiment a large lead-glass Cerenkov counter will be used.

ANTIPROTON INTERACTIONS IN NUCLEAR EMULSIONS

Warren W. Chupp and Sulamith Goldhaber

The scanning of the emulsion stack exposed to 700-Mev/c antiprotons has been continued. Five antiprotons were found in the part of the stack scanned by this group.

The salient features of the antiprotons are as follows:

1. The average energy release is somewhat greater than the rest mass of one proton, i.e., ~1 Bev.

2. One antiproton undergoes a large-angle scattering of 52°, finally comes to rest and annihilates. The kinetic energy of the antiproton at the scatter is ~80 Mev.

3. One antiproton gives an inelastic scatter with the emission of a low-energy proton and recoil. The energy of the antiproton before the scatter is about 210 Mev. The angle of the scatter is 15°. After traversing 5.2 cm of emulsion, the track leaves the stack. The angular criteria of entrance and the ionization of the particle, as well as the change of ionization in the path length traversed, indicate that the particle is most likely an antiproton.

Both the large-angle scatter and the inelastic scatter are of interest, since they show that nuclear interactions of the antiproton can take place without annihilation during the interaction.

PAPER PUBLISHED

A paper entitled "Mean Lifetime of the Negative K Meson," by Edwin L. Iloff, Gerson Goldhaber, Sulamith Goldhaber, Joseph E. Lannutti, F. Charles Gilbert, Charles E. Violet, R. Stephen White, D. M. Fournet, Aihud Pevsner, David M. Ritson, and Mildred Widgoff, has been published in Phys. Rev. 102, 927 (1956).

PHYSICS RESEARCH

Burton J. Moyer in charge

NUCLEAR CROSS SECTIONS FOR 4.3-Bev/c NEGATIVE PIONS

N. Fredrick Wikner and Hoyt A. Bostick

Transmission measurements of nucleon and nuclear cross sections were made by use of 4.3-Bev/c negative pions at the Bevatron during the latter part of March and the early part of April. Analysis of the data is incomplete; however, the following cross section values will not change very much.

(a) Total cross sections determined by subtraction techniques for nucleons were found to be:

$$\sigma_D = 50.8 \pm 3.7 \text{ mb},$$

$$\sigma_H = 28.2 \pm 3.5 \text{ mb},$$

$$\sigma_N = 23.2 \pm 3.2 \text{ mb}$$

for a target series CD_2 - CH_2 - C, and

$$\sigma_N = 22.7 \pm 3.3 \text{ mb}$$

for D_2O - H_2O difference.

(b) Total and absorption cross sections were determined as follows:

	Be	C	Al	Cu
σ_T (mb)	220	316	674	1620
σ_a (mb)	158	212	396	760

(errors ± 3% or 4% in each value).

Corrections have been made for a calculated muon contamination of 3.5% and for Coulomb losses in the total cross section measurements.

Calculations are continuing and a complete description of the experiment is being prepared for publication.

BEVATRON BEAM FINE STRUCTURE

John M. Brabant and Robert K. Squire

An investigation of the structure of the Bevatron beam with respect to the rf was made for various types of spill-out, and for various types of targets.

It was found that the introduction of noise into the rf to spill into a thick target produced an essentially dc beam over the entire width of the rf cycle.

A 0.1-mil rubber-hydrochloride target was tested in an attempt to get very high recycling factors. By keeping the rf on during spill-out, and steering the beam into the target, some recycling was obtained. Under these conditions the beam was intensely spiked into about one-third of the rf cycle. The peak-to-trough ratio was about 500. When "noise" spill-out was used with this thin target, a beam was observed which varied by a factor of only 2 from peak to trough.

By using a thin target (~ 1 kev dE/dx) on an outside-radius probe, one may be able to keep the beam bunched more tightly. Under these conditions the phase-stable protons may be made to remain in equilibrium because all of the energy lost by the protons by dE/dx in the target is restored by the accelerating system. Through the very high recycling factor possible ($\sim 10^5$), one may be able to make an effective target thickness of some tens of inches. Such a beam would necessarily have a limited phase region within the rf cycle.

π^0 MODES OF HEAVY-MESON AND HYPERON DECAY

John E. Osher and Sherwood I. Parker

The experiment to observe π^0 modes of heavy-meson and hyperon decay has been pursued. The technique was to use a previously described well-collimated gamma-ray telescope to observe the spatial variation in gamma-counting rate near a target exposed to high-energy protons at the Bevatron. The data were then interpreted through lengthy kinematics based on specific choices for models of associated production and unstable particle decay.

Briefly, the main contribution was consistent with $\theta^0 \rightarrow \pi^0 + \pi^0$, a mean lifetime of $1.9 \,^{+.2}_{-.3} \times 10^{-10}$ sec, a production angular distribution of the θ^0 involving angular momenta 7 ± 1 (i.e. $\cos^{14} \theta_{c.m.}$ terms for a preliminary best fit based on relative amounts of upstream and downstream contribution for the θ^0), and a cross section per nucleon in copper of $0.22 \pm .07$ mb for protons averaged from 5.7 to 6.2 Bev. Other details of the experimental curves imply presence of the θ^+ and Σ^+, and allow contributions from Λ^0.

Data for an excitation function have also been obtained and will be treated in a final report and in a publication under preparation.

PHOTON ENERGY SELECTOR FOR THE SYNCHROTRON

Robert J. Cence

The development of a photon selector discussed in the preceding Quarterly Report is being continued.

The selector counter in present use consists of a plastic scintillator located about 8 inches from the synchrotron internal target and viewed by a 6810 photomultiplier tube, located near the center of the synchrotron magnet, is mounted in a mu-metal shield surrounded by a 0.5-inch-wall water-cooled steel pipe. This magnetic shielding has proven adequate. Electronic problems are now the main source of difficulty. In particular, no satisfactory set of coincidence circuits has yet been developed to accommodate the extremely high counting rates involved.

COMPTON SCATTERING BY PROTONS

Larry L. Higgins

A pair of Cerenkov counters has been constructed for use in the proton Compton scattering experiment. These counters consist of blocks of about 50% lead content glass and are 12 inches in diameter and 6 inches thick. Gammas entering are converted to electron (±) - gamma showers, and the Cerenkov light emitted by the electrons is viewed by 15 type-6655 phototubes per block. A 250-Mev gamma produces typically a pulse of about 0.5 volt.

These counters are to be used to

(a) detect and roughly measure the energy of the scattered gamma ray,

(b) reject gammas from π^0 decay through their angular correlation when the synchrotron is above meson threshold.

CLOUD CHAMBER STUDIES

Wilson M. Powell in charge

Experiments with Diffusion Chamber

No additional runs were made during this quarter. Analysis of events previously obtained is continuing.

4.5-Bev π - p INTERACTIONS

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

"Production of a θ^0 Particle Without an Associated Hyperon in a π^- - p Collision" (UCRL-3321, Feb. 1956) reports the probable observation of a K^0 particle with strangeness -1. The existence of this previously unobserved particle is based on momentum- and energy-conservation calculations, and assumes associated production of strange particles.

n - p INTERACTIONS

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

An event was obtained by exposing the 35-atmos hydrogen diffusion chamber to the high-energy neutron beam at the Bevatron. The n-p collision shows three charged outgoing prongs and a Λ^0 that decays 1.6 cm from the colision. One of the charged prongs is an identified electron from ionization and momentum. A positive prong has approximately the same space angle (within 2.5°) as the identified electron and is assumed to be a positron.

If we assume that the Λ^0 and the electron-positron pair are the result of the fast decay of a Σ^0 meson produced in the n-p interaction, we compute a mass for the parent particle of $1235\ ^{+37}_{-24}$. The lower limit of our measurement is 20 Mev heavier than the accepted mass of the Σ^+ and 10 Mev heavier than the Σ^- mass reported by Gerson Goldhaber et al. The mass difference may be due to larger-than-normal turbulent distortion in the cloud chamber, or may help to show that the isotopic spin Σ triplet is slightly mass-degenerate. Alternate interpretations are being considered.

DECAY OF STRANGE PARTICLES PRODUCED IN HYDROGEN

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

The 35-atmos hydrogen diffusion chamber has been exposed to 4.5-Bev π^-, 5.3-Bev protons, and high-energy neutrons at the Bevatron. To date, 14 cases of production of unstable particles have been seen. There is only one case showing two decaying particles. Its interpretation is

$$\pi^- + P \rightarrow \theta^0 + \Sigma^+ + \pi^- + \pi^0.$$

In nine of the events of unstable-particle production, charged-pion production is also seen or neutral-pion production is inferred from momentum conservation. In the remaining five cases, it is impossible to determine whether pion production also occurred.

Of the 14 decays observed, there are six θ^0's, five Λ^0's, one Σ^+, one V^0, one K^-, and one V^+.

DECAY OF STRANGE PARTICLES PRODUCED IN STEEL

Baxter Armstrong

From the same high-pressure diffusion chamber runs as above, a number of pictures of V-particle decays in which the particle was produced in the steel wall of the chamber have been seen. Measurement of the decays started in January and for the neutral V's is essentially finished. A categorical analysis shows 67 Λ^0 and 52 θ^0 decays, 34 decays that are indistinguishable either kinematically or by ionization, 13 still uncertain, and 4 "anomalous" decays, giving a total of 170 neutral V's. Forty-one charged V's have been seen and measured. Analysis of these events is now under way.

The computer program of analysis is being set up for the neutral V's. Among the more interesting quantities to be computed are angular distribution of decay products in the center-of-mass system, and the distribution of the angle between the decay and production planes. It is planned to carry out the major part of this analysis on the IBM 650 computer.

Experiments with Expansion Chamber

MULTICHAMBER EXPERIMENT

H. Courant, John Elliot, William B. Fowler, John Ise, and Wilson Powell

During K^- counter running at the Bevatron a multichamber expansion cloud chamber scheme was set up and operated. The magnet chamber was furnished by the cloud chamber group and the multiplate chamber was the chamber previously used by Ise and Pyle. The geometry we used placed the magnet chamber first in order to make momentum measurements, and the multiplate chamber second for stopping the deflected particles. Such a scheme has been used many times for mass measurements. The goal of the experiment is to measure the masses of decay products of heavy unstable particles. The success of the experiment is dependent upon finding a beam in which the flux of heavy unstable particles is sufficiently high for us to see decays despite the slow repetition ratio (approximately 1 to 2 per minute) of the expansion chambers.

Equipment and Techniques

HYDROCARBON BUBBLE CHAMBER

Larry Oswald and Wilson Powell

The propane chamber was operated during this quarter. Various electronic difficulties were encountered during the operation and have subsequently been solved. Pictures were taken during the first run and tracks were observed. The chamber conditions were not very stable, owing to the unreliable electronics, so the tracks were not as clear and sharp as expected. We planned to make a second run shortly after the first one, but it was discovered that the metal filler between the top glass and the clamping ring had flowed during the first run and allowed the top glass to move far enough away from the chamber so that the chamber leaked.

The chamber is now assembled with epon between the glass and the clamping ring. This assembly has been tested at operating temperature and twice the operating pressure, and has not flowed in any measurable amount.

The secondary pressure tank that is to be used during Bevatron operations is nearing completion and will be tested this quarter.

PHYSICS RESEARCH

Chaim Richman in charge

K-MESONS

Ranges of Secondaries, Abundances of Decay Modes, and Masses

Two papers are being prepared for publication on the data obtained from the large emulsion stack previously described. The first, based on Jim Peterson's thesis (UCRL-3368), contains the mass measurements made by the range-momentum method on the six positive decay modes. The inherent resolution of the magnetic spectrometer and the necessary corrections to be made are discussed in detail. The second paper contains information gained from measurements on the secondaries. Included are the range measurements on 23 stopped K_{π}^2 and 20 $K\mu_2$ secondaries, and the data on the relative abundances of decay modes obtained through following and blob-counting K secondaries. The masses of the K_{π}^2 and $K\mu_2$ are calculated from the Q of decay. (Table I gives a summary of the data on masses, and abundances.) In view of the particular interest in the K_{π}^2 - τ mass difference all π secondaries were measured twice. The individual ranges agreed to within 300 microns, or 0.3%.

Table I

Summary of data on masses and abundances of K particles

Particle type	Range momentum	Secondary Q	Abundances of all K's (%)
$\tau + \tau'$	966.6 ± 1.9[a]	---	7.7 ± .6[a]
$K_{\pi 2}$	966.7 ± 2.0	962.8 ± 1.8[a]	28.0 ± 2.7
$K\mu_2$	967.2 ± 2.2	965.8 ± 2.4	60.0 ± 3.1
$K\mu_3$	967.6 ± 6	---	2.6 ± 1.0
$K_{\beta 3}$	964 ± 10	---	1.8 ± 1.3
τ	966.3 ± 2.1	966.1 ± .4	5.56± .42
τ'	967.7 ± 4.0	---	2.17± .49
All	966.8 ± 1.1	---	100

[a] Errors are statistical standard deviations of the means

τ-Meson Analyses

A second one hundred τ mesons are being analyzed according to the Dalitz and Fabri schemes to determine the spin and parity. When these data are added to those previously obtained, which indicated 0^-, good discrimination will be had for all low-spin cases.

Scattering

A K-hydrogen scattering experiment is being planned. The hydrogen target is nearly completed. The total attenuation will be found by using scintillation counters; for the differential scattering cross section a nuclear emulsion stack will be used as a detector.

ANTIPROTONS

Antiproton Stack

The stack exposed in the "separated" p^- beam, mentioned in the last quarterly report, is now half scanned. One definite antiproton annihilation was found at rest and one probable annihilation one centimeter after entering the stack. If we use the 2x geometrical cross section for beryllium, the number we would have expected to find is 8 ± 5 antiprotons.

Cooperative Antiproton Exposure

The cooperative antiproton stacks have been rescanned. One new event was found, compared with seven in the first scanning. Thus, the scanning efficiency has been quite high. Further analysis of the stars has been completed and an abstract (UCRL-3313, Abstract) was submitted to the Washington meeting of the American Physical Society.

PHYSICS RESEARCH

Emilio Segrè in charge

ANTIPROTON EXPERIMENTS

Clyde Wiegand

No additional experiments have been done, but the analysis of the irradiated emulsion stacks has continued and further results are reported below. We have continued the construction of apparatus for future antiproton experiments.

Antiproton Beam

The calculation of trajectories to be obtained with the 8-inch-aperture quadrupole magnetic lenses, which are under construction, has been completed by L. Agnew and E. Rogers. If only the improved geometry is taken into account the intensity of the expected beam should be about 80 times that of the original setup. The number of antiprotons should be about 2000 per day of average Bevatron operation.

Antiproton Attenuation in Hydrogen

A liquid hydrogen target with styrofoam insulation has been constructed. The target (9 by 9 by 36 inches) holds 42 liters of hydrogen in a stainless steel container.

Antineutron Experiment

The construction by R. Weingart of a multilayer detector to record electronically the energy of nucleon-antinucleon annihilation is proceeding. The apparatus consists of 48 counters 12 by 12 by 2 inches. Each unit contains 6 sheets of plastic scintillator 0.25 inch thick interleaved with 5 sheets of lead 0.090 inch thick. The units can be stacked into a block 24 by 24 by 24 inches which should contain most of the annihilation products.

STUDY OF ANTIPROTONS IN NUCLEAR EMULSIONS

A. Gösta Ekspong and Gerson Goldhaber

As part of a general cooperative program to study antiprotons in nuclear emulsions we have found 15 examples of antiproton annihilations in our part of Stack 68, exposed to the 700-Mev/c negative particle beam.* The first star is described in detail in the UCRL-3325. Five of the antiprotons came to rest (ranges about 12 cm), and ten annihilated in flight. One track underwent a 47° inelastic scattering, producing a small 2-prong star.

Among the prongs of these 15 P^{-} stars one K particle was definitely established and one possible K particle was found. Track No. 8 of star No. 4 has a dip angle of 11° and travels for 2.5 cm in the stack and then disappears in flight. Because of this favorable low dip angle and low kinetic energy

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* This exposure was carried out by Owen Chamberlain, Warren W. Chupp, Gerson Goldhaber, Edward J. Lofgren, Emilio Segrè, and Clyde Wiegand and is described in UCRL-3325.

(78 Mev), reliable multiple scattering and ionization measurements were possible; they gave a mass consistent with the τ mass.

Table I gives some results, as presently available on the P^- stars. The following notation is used: W = total available energy = $2 M_p c^2 + T_{P^-}$ (in Mev), f = visible energy/W.

Table I

Antiproton stars in Stack 68						
Multiplicity	Track Analysis			Energy Balance		
No. $\pi + N^o$(P, D, T)	No.	Identity	Kinetic energy (Mev)	Visible energy (Mev)	W (Mev)	f
Star No. 1, (at rest), Jan. 11						
$5\pi+3$	1	P?	10			
	2	π^-	43			
	3	π?	174±40			
	4	P?	~70	1300±50	1868	0.70
	5	π^+	30±6			
	6	T?	82			
	7	π^-	34			
	8	π?	125±25			
Star No. 3, (at rest), Jan. 23						
$2\pi+1$	1	Recoil	---			
	2	π?	470±150			
	3	He?	~2	1050±240	1868	0.56
	4	π?	300^{+200}_{-170}			
Star No. 4, (in flight), Jan. 25						
$2\pi+1$ K + 7	1	π?				
+1(K or P)	2	π?				
	3	P?	6.1			
	4	Recoil	--			
	5	P?	17.5			
	6	P?	16.5		2045	
	7	P?	15.0			
	8	K	78			
	9	P?	7.0			
	10	P?	4.0			
	11	K or P	analysis not completed			
	12	P?	13.4			

Table I continued

Antiproton stars in Stack 68

Multiplicity	Track Analysis			Energy Balance		
No. $\pi + N^{o}(P, D, T)$	No.	Identity	Kinetic energy (Mev)	Visible energy (Mev)	W (Mev)	f
Star No. 5(in flight)Jan. 25						
$0\pi+6$	1	P?	3.5			
	2	P?	240			
	3	P?	8.3			
	4	P?	63	372	1940	0.19
	5	P?	3.7			
	6	P?	6.2			
	7	Recoil	--			
Star No. 8(in flight)Feb. 13						
$3\pi+5$	1	π?	225±25			
	2	P?	12.5			
	3	P?	8.2			
	4	P?	22.0	1700±400	2184	0.78
	5	π?	540±400			
	6	P?	3.6			
	7	π?	>420			
	8	P?	9.2			
Star No. 9(at rest)Feb. 20						
$4\pi+1$	1	P?	17			
	2	π?	120±25			
	3	π?	115±15	$1048^{+?}_{-80}$	1868	0.56
	4	π	78±12			
	5	π	$150^{+?}_{-70}$			
	6	Recoil	---			
Star No. 10(in flight)Feb. 22						
$2\pi+1K+6$	1	P	9.7			
	2	He?	12			
	3	K?	180			
	4	P??	very slow	1132	2013	0.56
	5	P?	38			
	6	P?	3			
	7	π	52±13			
	8	P	40			
	9	π	135±22			

Table I continued

Antiproton stars in Stack 68						
Multiplicity	Track Analysis			Energy Balance		
No. $\pi + N^{o}(P, D, T)$	No.	Identity	Kinetic energy (Mev)	Visible energy (Mev)	W (Mev)	f
Star No. 11(in flight)Mar. 14						
$5\pi+1$	1	π?				
	2	P?	6.2			
	3	π^{+}	75		2063	
	4	π	300^{+150}_{-125}			
	5	π	140 ± 18			
	6	π?	115 ± 65			
Star No. 12(at rest)Mar. 16						
$4\pi+1$	1	π?				
(?)	2	π?				
	3	π?			1868	
	4	P?				
	5	π?				
	6	Recoil				
Star No. 13(in flight)Mar. 19						
$2\pi+4$	1	P?	86			
	2	P?	8			
	3	P?	2.4	597 ± 80	1937	0.31
	4	P?	3.0			
	5	π?	155 ± 75			
	6	π	31 ± 6			
Star No. 16(in flight)Mar. 22						
$2\pi+0$	1	π?	~300	~720	1944	0.37
	2	π?	140 ± 60			
Star No. 17(in flight)Mar. 28						
$3\pi+5$	1	P?	6.7			
	2	π	72 ± 15			
	3	P?	7.6			
	4	P?	24	988 ± 50	2068	0.48
	5	π	93 ± 15			
	6	P?	21			
	7	P?	4.6			
	8	π?	300 ± 40			

Table I continued

Antiproton stars in Stack 68						
Multiplicity		Track Analysis			Energy Balance	
No.	π + N^o(P, D, T)	No.	Identity	Kinetic energy (Mev)	Visible energy (Mev)	W (Mev)	f
Star No. 18(at rest)April 9							
	5π+0	1	π?				
		2	π?				
		3	π?			1868	
		4	π?				
		5	π?				
Star No. 19(in flight)April 27							
	4π+4	1					
		2					
		3					
		4				2008	
		5					
		6					
		7					
		8					
Star No. 20(in flight)May 10							
	not yet analyzed	1					
		2					
		3					
		4					
		5					
		6				2020	
		7					
		8					
		9					
		10					
		11					
		12					
		13					

REPORT ISSUED

A paper by J. Baldwin, O. Chamberlain, E. Segrè, C. Wiegand, R. Tripp and T. Ypsilantis (UCRL-3399) describing the deuteron-nucleus double-scattering experiments has been prepared for publication in the Physical Review. The experiments failed to detect the expected tensor components of the deuteron polarization. Measurements were made of the elastic differential scattering cross section and the vector polarization from 94 to 157 Mev with Li, Be, C, Al, and Cu targets.

ACCELERATOR OPERATION AND DEVELOPMENT

BEVATRON

Edward J. Lofgren in charge

DEVELOPMENT RESEARCH

Charles W. Causey, Jr., Bruce Cork, and William A. Wenzel

Three experiments relating to the use of the Bevatron have been performed.

Induction Electrode

The east induction electrode has been calibrated from the known capacity-to-length ratio of the electrode and the observed "duty cycle" of the circulating beam. With an ordinary signal generator and a good radio-frequency voltmeter, the circulating beam can be measured with less than 10% error for energies above 900 Mev. The recorder in the counting area and the control-room oscilloscope presentation from the south tangent tank are best calibrated by comparison with the signal from the east electrode. The noise-level background of the east electrode system has been reduced by improved circuit isolation to about $5 \cdot 10^6$ protons per pulse.

Fast Structure of the Beam

The radiofrequency structure of the beam spill-out has been measured by comparing the phase of the coincidence signal from a counter telescope viewing the internal target with the signal from the master oscillator. The rf signal was squared and fed with 180° relative phase shift onto one grid of each of two gating tubes. The telescope coincidence signal was fed onto the other grid of each tube. The ratio of counts in the channels was plotted as a function of the total delay of the master oscillator signal. The maximum and minimum values of this ratio occurred 180° or 0.2 microsecond apart, as expected. For various methods of beam spill-out, the results are given in Table I. All measurements were made with a beam energy of about 3 Bev.

It is seen that the fast structure of the beam depends largely on whether the accelerating radiofrequency is on or off at the time of spill-out.

Effect of the Clipper

A monitor telescope viewed a 3-by-1-by-1-inch polyethylene target with a plastic scintillator "lip" 1 by 0.5 by 0.25 inch (to damp the betatron oscillations of the initial circulating beam). The telescope counting rate, which is proportional to the amount of beam passing through the target, was measured as a function of the radius to which the clipper was plunged. That the copper clipper, which is 4 inches thick, is effective in degrading or stopping the beam is indicated by the fact that the counting rate fell to about 2% of the maximum value when the clipper was plunged to a radius outside the target radius. A proton making a single pass through the target in the

Table I.

Spill-out method: (radiofrequency change)	Magnet current characteristics	Over-all spill time (milliseconds)	Target material	Maximum ratio / Minimum ratio
Turned off sharply	Flat top (slow rise)	≈ 30	1-in. Ta	1.0
Turned off sharply	Usual rise	≈ 1	1-in. Ta	1.1
Not turned off	Usual rise	≈ 50	1-in. Ta	25
Not turned off	Usual rise	≈100	0.0005-in. mylar foil	2
Amplitude reduced	Usual rise	≈ 50	1-in. Ta	6
1 kc noise added to radiofrequency	Usual rise	≈ 50	1-in. Ta	8

west straight section should lose enough energy to pass through the east straight section several inches inside the target radius. That this actually happens seems to be indicated by the appearance of a fair plateau in the counting rate for clipper positions several inches inside the target radius (Fig. 1). At high energies, if the clipper is not plunged, about two target traversals on the average per beam particle seem to occur for the target thickness and location used in this experiment. Measurements were made at 2.24, 4.40, and 6.2 Bev.

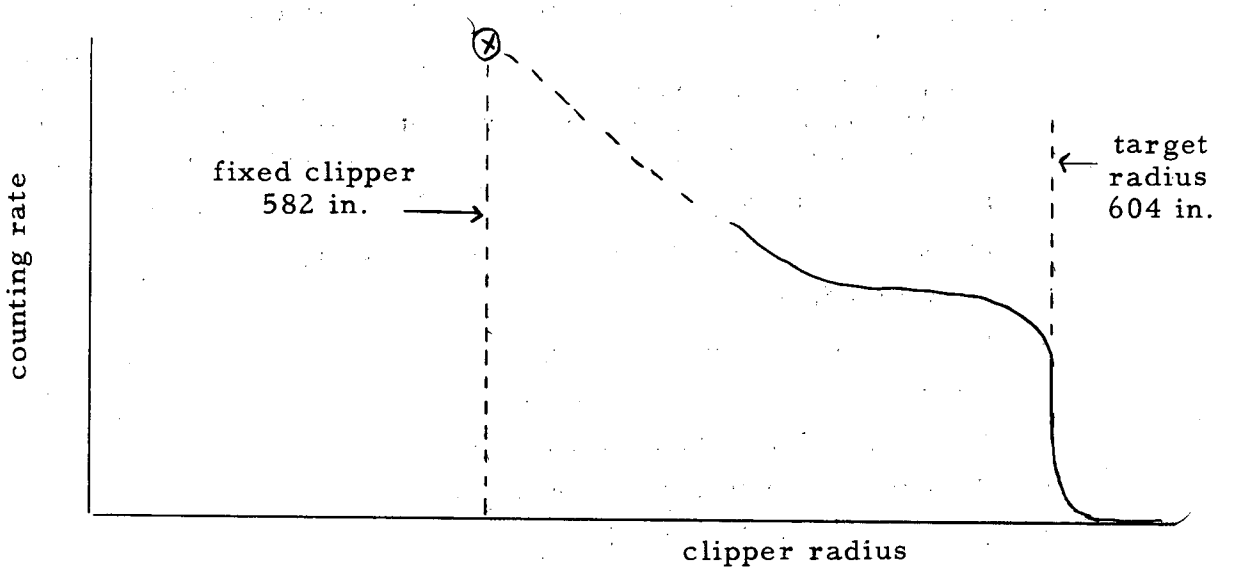


Fig. 1. Counting rate as a function of clipper position.

OPERATION

Further progress in the Bevatron program is the subject of a separate report by Walter D. Hartsough, "Bevatron Operation and Development. VIII," UCRL-3332, March 1, 1956.

184-INCH CYCLOTRON

Robert L. Thornton in charge

MODIFICATION

Richard Burleigh

The following work on the modification has been finished during this quarter:

1. Reinstallation of dee tank.
2. All work on main coils, including oil-leak repair.
3. All work on auxiliary coil installation.
4. All work on installation of pole-tip discs and shims.
5. Completion of magnet force tests, during which both main and auxiliary coils were run up to 110% of rated current with rough vacuum in the dee tank. Stresses in bolts, change in gap, and central field are all very satisfactory.
6. Erection of meson cave wall, including slot shielding.
7. Installation of four of the six diffusion pumps.
8. Design of final movable panels.
9. Magnetic deflector test section.
10. Copper plating on new vibrating blades.

Work is in progress on the following items:

1. Design of final transmission lines.
2. Design of steering magnet.
3. Design of temporary vacuum barrier between capacitor tank and dee tank.
4. Assembly of new blades on motors for balancing.
5. Magnet regulator tests.
6. Assembly of final movable panels.

60-INCH CYCLOTRON

Joseph G. Hamilton in charge

DEVELOPMENT: DEFLECTOR CHANNEL PROBE

G. Bernard Rossi, Charles A. Corum, and William B. Jones

For some users of the cyclotron it is desirable to obtain a highly focused beam. A magnetic strong-focusing system has been used on the extracted beam, resulting in a beam density of over 5 $\mu a/cm^2$ with an energy spread of approximately 1%. This beam density, however, is not high enough for some users. By measurement of the beam density at various points along its trajectory it was found that the highest degree of focusing of the deflected beam that could be readily used was located axial to the centerline of the dees as the beam passes from the deflector channel to the target chamber (see Fig. 2).

Measurements of the deflected beam at R = 29-13/16 inches demonstrates the degree of focusing attained. The full width of the vertical intensity distribution has been measured as 0.05 inch at the 70%-intensity points. Beam densities of 140 $\mu a/cm^2$ of 48-Mev helium ions were measured by the transmission of 7 μa of beam through a 1/32-by-1/4-inch horizontal slit. A peak density, under similar conditions, of 215 $\mu a/cm^2$ has been recorded.

Special equipment had to be designed to effectively utilize this high-density beam for irradiations of rare radioactive materials. Requirements were that the target material be completely isolated from the cyclotron vacuum system; that all components be either water-, air-, or helium-cooled; and that the target be within an evacuated space to permit transmission of recoil particles.

The photographs of Fig. 3 show the probe target designed to the above specifications. It consists of a precollimator (A) and a vacuumtight target holder (B) mounted for separate removal. During bombardment, as high as 80 μa of 48-Mev helium ions impinge upon A, creating beta-gamma activity of the order of 500 to 1000 roentgens per hour.

The target holder itself consists of a collimator (C), vacuum window (D), target-bearing foil (E), and recoil catcher (F). The collimator holders (A and C) are water-cooled and were prepared to hold graphite slits cut horizontally to accept maximum beam. The slot of the collimator (C) has been as small as 1/32 by 1/4 inch, allowing from 8 to 10 μa of 48-Mev helium ions to be transmitted to the target.

The space between foil holders D and E (1/4 inch) is provided with inlet and outlet openings to permit the flow of cooling air or helium; the chamber G, containing the target material and catcher foil, can be evacuated to increase the range of recoil particles. The vacuum seals between sections were made with slip-fitting O-ring holders, permitting maximum flexibility for changing foils and target materials. For such slip-fitted seals, tolerances of the order of 0.002 inch were necessary on all surfaces.

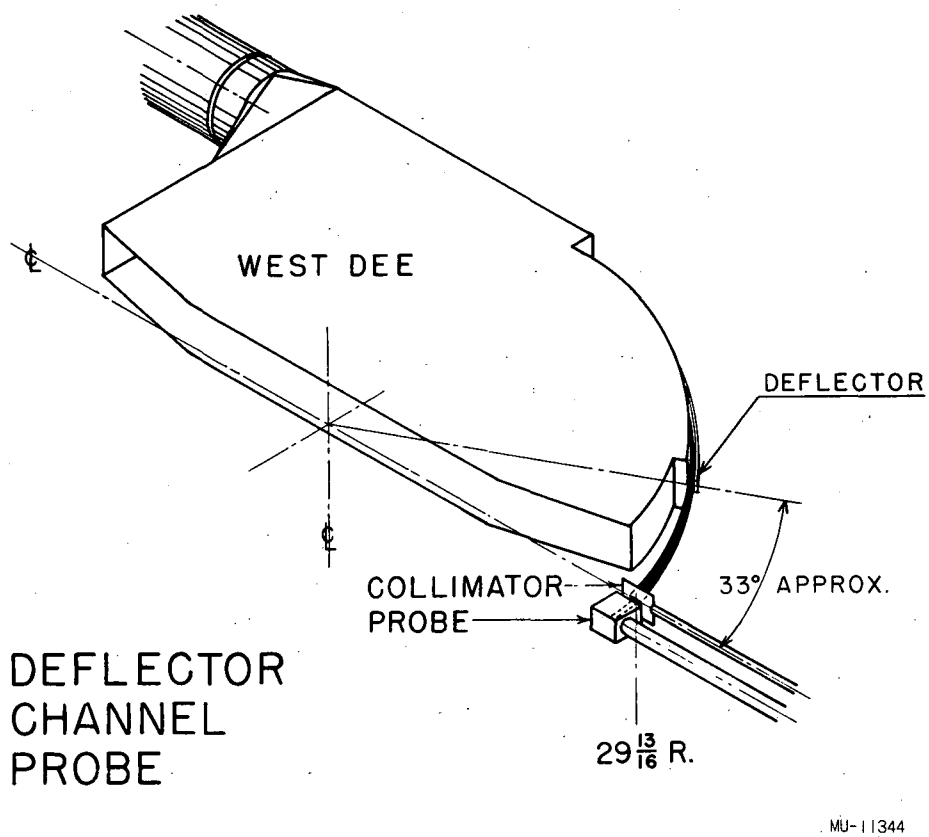
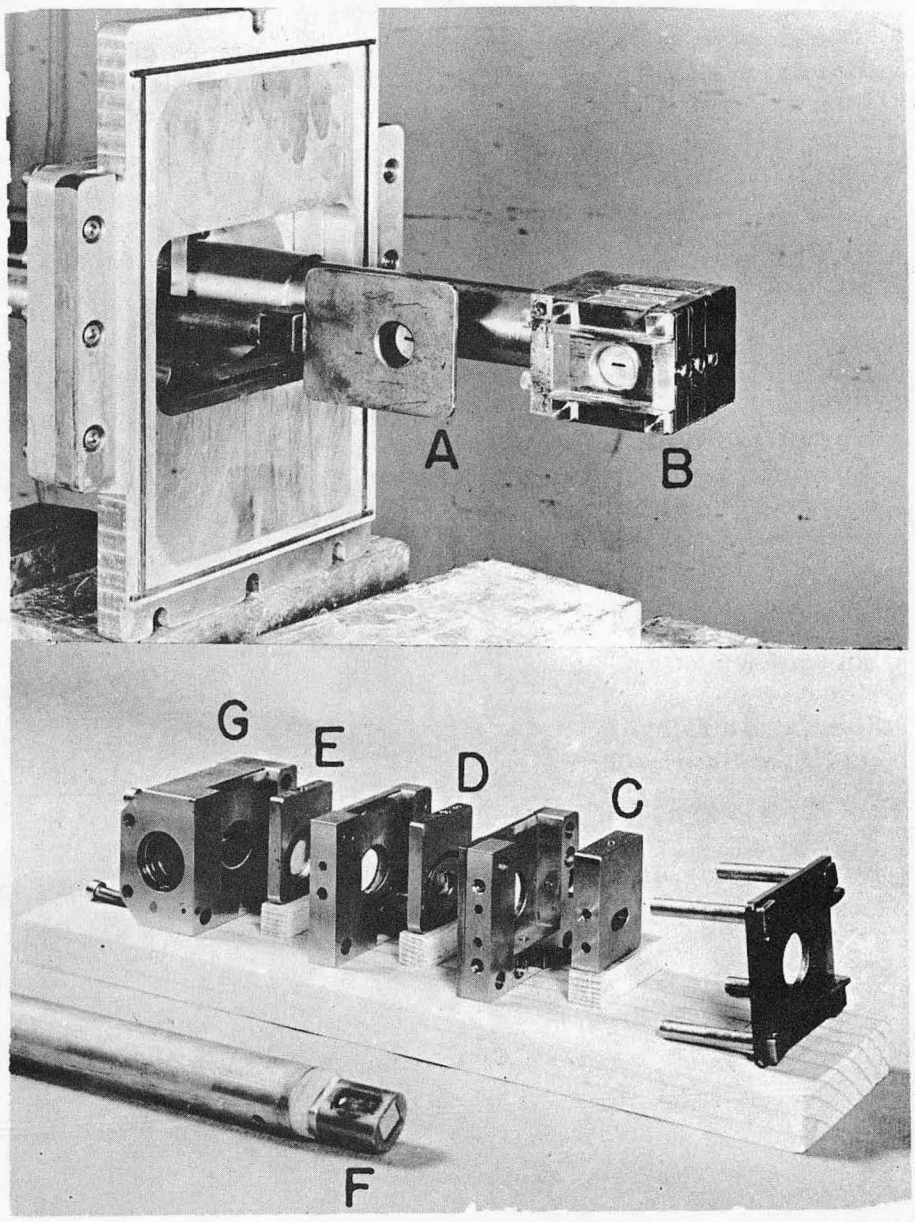


Fig. 2. Deflector channel probe.



ZN-1504

Fig. 3. Internal deflected beam probe.

A series of irradiations have been made, using this equipment with 48-Mev alpha particles. The identification of element No. 101[1] and many other transuranic bombardments[2] have been done with this probe. As beam levels were increased, circulating helium supplanted air cooling between holders D and E; water cooling replaced air in the recoil catcher.

The design of the probe was the joint effort of Charles A. Corum and G. Bernard Rossi of Crocker Radiation Laboratory, and Alfred Ghiorso of the University of California Radiation Laboratory Chemistry Group.

OPERATION

Summary of operations as prepared by Peter McWalters for this quarter:

Alpha bombardments		495.9 hr
Deuteron bombardments		132.3 hr
Proton bombardments		248.6 hr
Beryllium bombardments		129.6 hr
Nitrogen bombardments		7.9 hr
Experimental bombardments		22.2 hr
	Operational total	1036.5 hr
Outage time		161.9 hr
	Available time	1198.4 hr
Shutdown		940.6 hr
Holiday		16.0 hr
Special shutdown		4.0 hr
Daylight Saving Time		1.0 hr
		2160.0 hr

An operating efficiency of 86.5% was maintained throughout this quarterly period.

[1] Ghiorso, Harvey, Choppin, Thompson, and Seaborg, Phys. Rev. 98, 1518-1519 (1955).

[2] Chetham-Strode, Choppin, and Harvey, Mass Assignment of the 44-Minute Californium-245 and the New Isotope Californium-244, UCRL-3219.

LINEAR ACCELERATOR

James Donald Gow in charge

DEVELOPMENT: ENERGY STABILIZATION

H. Brook Knowles

The components of the energy-stabilizing system for the linear accelerator have been built and for the most part tested. The energy-sensing ionization chamber tested out quite satisfactorily; however, the scattering foil used was aluminum and at the small angle (4°) there appeared to be a measurable contribution from the 845-kev level, which caused an effective flattening of the ionization curve on the low-energy side of the ionization peak. Gold or platinum foil will be used to overcome this.

The paddle drive and control assembly has been built and bench tested. It was installed in the machine. For a paddle approximately 3 by 4 inches located 5 feet from the exit end of the tank, it was found that the proton energy could be changed by approximately 250 kev in a 90° rotation of the paddle. The variation is approximately sinusoidal.

OPERATION

The 32-Mev linear accelerator continued to operate on a normal research schedule during this quarter. A short shutdown was made to install variable loops on two oscillator positions. The Van de Graaff deuteron beam was used for neutron-production experiments. It was found that radiation levels in the control room became excessive with full-current D beams, and more shielding will have to be installed if high-current D beams are used.

Work on an energy-control scheme for the 32-Mev beam continued. The design was completed and most of the parts were finished and tested prior to May 1.

SYNCHROTRON

Edwin M. McMillan in charge

RESEARCH PROGRAM

Robert W. Kenney

The first phase of the investigation of the π^+ photoproduction in complex nuclei at 135° in the laboratory system has been completed by William Imhof, Edward Knapp, and Victor Perez-Mendez. The mean free path for π^+ mesons in nuclear matter has been derived as a function of meson energy. The angular distribution for π^+ photomesons from complex nuclei will be investigated in the near future. This work, which is Imhof's thesis, has appeared as UCRL-3383, May 1956.

The first phase of the investigation of the π^0 photoproduction in complex nuclei at 135° (lab) has been completed by John Anderson and Robert Kenney. The mean free path for π^0 mesons in nuclear matter has been derived as a function of meson energy. The angular distribution for π^0 photomesons from complex nuclei will be investigated in the near future. This work, which is Anderson's thesis, is to appear as UCRL-3426, May 1956.

Robert Cence has been developing a counter to identify the energy of single electrons after they produce bremsstrahlung in the synchrotron internal target. It is expected that a photon or an event caused by a photon can be time-correlated with the individual electron which produced that photon. The photon energy can therefore be identified and interactions between complex nuclei and photons of known energy in the 250-Mev energy range then become observable in a clean manner.

Walter Dudziak, Norris Nickols, and James Vedder have completed a study of the π^-/π^+ ratio from deuterium at 90° (lab) and at meson energies as low as 12 Mev. The large spiral-orbit spectrometer was employed to identify the meson energies.

William Imhof, Robert Kenney, Edward Knapp, and Victor Perez-Mendez have investigated experimentally the possibility of observing the π^+ photoproduction from hydrogen and deuterium at 0° by counting mesons with the π-μ apparatus during the beam pulse. It was concluded that it is feasible to measure the angular distribution for the reactions $p(\gamma, \pi^+)n$ and $d(\gamma, \pi^+)2n$ from 0° to 45° (lab). A liquid hydrogen target is now under construction.

R. Stephen White and Harold Furth, a graduate student from Harvard who visited the laboratory, investigated the exposure of nuclear emulsions with transient magnetic fields of 200,000 gauss present at the emulsions during the synchrotron beam pulses. Satisfactory results were obtained and this equipment will be used later for K-meson exposures at the Bevatron.

OPERATION

Rudin M. Johnson

The synchrotron has been used for physics research experiments during this period at full- and half-energy levels. The beam intensity has been high, delivering an estimated 5×10^8 electrons per pulse to the target with a corresponding photon beam of 2.5×10^9 Mev/pulse through a 0.75-inch collimator.

The synchrotron beam was pulsed successfully at a 3 ppm rate for the Furth and White nuclear plate experiment (which used a pulsed high-field magnet) by gating on the rf oscillator once every 120 magnet pulses.

When time could be spared from the physics program, the synchrotron-magnet voltage regulator was tested. Its operation thus far is unstable and not usable in regular operation. More debugging time is needed.

The target quartz was cracked during a target change that was made for the Anderson and Kenney experiment. The synchrotron was taken apart and the cracked quartz replaced with a spare. A new resonator was also installed which had been specially shielded to reduce the rf radiation from the scribe lines. A shaker coil was added to the upper pole tips, which will be used to capture more beam at injection time. Some of the upper octant coils were repaired. The synchrotron was assembled and enough beam intensity was found to continue physics experiments with only one week's loss of time.

The linac No. 2 has been completed and has produced electron beam energies of 5.5 Mev maximum. The linac has not been operated yet at high currents or repetition rates for long periods because heavy enough shielding is not available. A concrete radiation vault large enough for physics and chemistry experiments is being designed. The electron beam size is less than 1/8 inch in diameter, and peak currents of 100 milliamperes have been measured for short periods.

The new klystron for the 2-Mev linac injector has been delivered and tested. This klystron was also operated at 21-μsec pulse lengths for tests made for Wilmot Hess at Livermore. The results indicate that the klystron will operate at 21 μsec pulse length.

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