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UNIVERSITY OF CALIFORNIA

Radiation Laboratory

PHYSICS DIVISION QUARTERLY REPORT
November, December 1955, January 1956

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* Preceding Quarterly Reports: UCRL-3223, UCRL-3115

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GENERAL PHYSICS RESEARCH

PHYSICS RESEARCH

Luis W. Alvarez in charge

K-MESON LIFETIME EXPERIMENT

Luis W. Alvarez, Frank S. Crawford, Myron L. Good, Robert D. Tripp, and M. Lynn Stevenson

A preliminary run with a new K-particle beam was held to investigate the properties of the beam. The beam uses 4-inch-aperture quadrupoles and a bending magnet of large (7-inch) gap. The results obtained were that the focusing properties and intensity behaved as expected, and are improved over the former arrangement.

PION INTERACTIONS IN HYDROGEN (4-INCH BUBBLE CHAMBER)

Hugh Bradner, Frank S. Crawford, Myron L. Good, and M. Lynn Stevenson

As a preliminary to a proposed, but now canceled antiproton experiment with the 4-inch bubble chamber, some running time in the 710-Mev π^- beam of the Kerth-Stork antiproton experiment was obtained.

Approximately fifty pion interactions in hydrogen were observed and are being analyzed.

PROGRESS ON $C^{12}(p, \alpha) B^9$ REACTION MEASUREMENT

H. Brook Knowles

This period has been devoted to measuring and attempting to correct the energy drifts in the linear accelerator. A run in the first part of November established:

(1) That the beam energy is quite sensitive to the plate voltage in the drift tubes (rising about 400 kev per kv of plate voltage).

(2) That the beam energy is essentially independent of the Van de Graaff injection energy.

(3) That the most powerful energy control lies in the tuning of the exit cavity (the energy varies about 20 kev per mil of deplacement of the tuner, increasing as the end tuner is moved in).

(4) That the beam energy spread is no greater than 200 kev and probably of the order of 150 kev full width at half maximum. (This number was later confirmed independently by a magnetic analysis done by Stirling Colgate.)

An energy-measuring device using protons elastically scattered at angles of 3° to 5° off the exit foil of the scattering chamber is under construction. This device is essentially a scaled copy of one used at Princeton to measure the energy of the 18-Mev cyclotron.[1] The electronic circuit is constructed and being tested at this time. Members of the Linear Accelerator Group are designing a servo system to operate a paddle which is to be inserted in the last cavity and perform a returning operation (without the need of moving the end tuner), which will give a negative feedback. It is believed that a stabilization of the energy within at least ± 25 kev can be obtained in this way.

In addition, other methods of analyzing an energy spectrum of particles have been calculated. A six-channel differential range counter is designed and will be built if time permits. Also, magnetic analysis has been examined, but will probably not be considered further in view of the probable removal of the machine from this project in the near future.

DIRECTION OF SPIN POLARIZATION IN CYCLOTRON PROTON-NUCLEUS SCATTERING

Hugh Bradner and W. Isbell

We have completed measurements on an experiment similar to those by Marshall and by Rose in which a high-energy beam of protons with polarization of known magnitude but unknown orientation was slowed to approximately 10 Mev and scattered in helium. The left-right scattering asymmetry for arbitrary incident-beam polarization can be predicted from phase shifts computed from proton-helium scattering experiments.

We have used polarization computed from the phase shifts, including d waves, of low-energy scattering experiments. The observed asymmetries agree with the predictions by Fermi and the results from Marshall; viz., a polarization of the direction that would be produced by spin-orbit coupling in the nuclear shell model. A check experiment was made with identical conditions except that an unpolarized proton beam was used. The nuclear plates from this experiment have been analyzed and the data are being worked up.

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[1] G. Schrank, Rev. Sci. Instr. 26, 677 (1955).

LIQUID HYDROGEN BUBBLE CHAMBERS

Luis W. Alvarez, James Donald Gow, and group

10-Inch Chamber

The major effort during this quarter has been directed toward operation of the 10-inch chamber. Early in November the first 10-inch-chamber test run with liquid hydrogen was made. This experiment was set up in a temporary test building constructed adjacent to Building 64. All the mechanical and electronic control components operated in a satisfactory manner. The expansion system gave adequate expansion ratios and tracks were produced in the hydrogen. The chamber was operated over a period of two days before the run was terminated by internal mechanical failure of the expansion valve. During this run pulse rates as high as 4 per minute were produced.

Immediately after the first test run, the chamber was fitted to the old cloud-chamber magnet in the Bevatron building. This work was completed in December and a test run was made using a 2-Bev π^- beam from the Bevatron. This run demonstrated that the chamber was not sensitive to minimum ionizing particles throughout its depth. No difficulties of mechanical or control nature were experienced.

Several modifications were made in the apparatus in an attempt to get uniform sensitivity. Included in these were improved shielding to reduce thermal radiation from the camera window, and a cold valve to permit control of the temperature of the expansion-line 20° K heat exchanger. A third run was made, but no improvement of the nonuniform sensitivity was noted. During this third run, tests proved that the lack of uniform sensitivity was due to a heat-transfer mechanism that had been ignored.

Bubbles that form in the bulk of the liquid during the sensitive phase extract heat from the surrounding liquid to provide the heat of vaporization. This energy is then transferred to the top of the chamber as the bubbles rise. Upon recompression the heat is given up near the top. The result is that a few expansions produce a thermally stable temperature gradient in the liquid, the top of which is at the highest temperature.

Three corrective measures are being put into the system to cope with this problem. One of these is a stirring paddle, which could be used to mix the liquid hydrogen prior to each pulse. The second is a fast recompression system. It is hoped that the chamber can be recompressed before the bubbles have risen appreciably from their points of formation. The third cure consists of a tube inserted through the chamber wall at the highest point which will, during recompression, exhaust the gaseous hydrogen to an external heat exchanger. The latent heat will then be absorbed and dissipated outside the chamber. All of these will be tested during a run to be made in February.

4-Inch Chamber

The 4-inch chamber was used to study interactions of 700-Mev negative pions in hydrogen in a run made in December. One week of intermittent running time, using every 10th pulse from the Bevatron, gave enough events to yield a reasonably good scattering angular distribution. The data from this run are still being analyzed. Since that run the 4-inch chamber has been used to test new illumination systems and to measure the rate of rise of bubbles in liquid hydrogen. Preliminary data indicate that the small bubbles formed along the track of a nuclear particle rise about 0.5 cm in 50 milliseconds.

Test Programs

The window-seal test program has been completed with the successful operation of an inflatable stainless steel "inner tube"-type seal. This seal is believed to be the one that will be used on the 72-inch chamber window. By control of the pressure of helium gas in the "inner tube," the window seal can be clamped or released. This permits a chamber-and-window assembly to be cooled without encountering large forces due to differential expansion, as the seal is made after the assembly is cold.

A liquid expansion system, which is a model for the expander to be used on the 72-inch chamber and is also designed for later installation into the 10-inch chamber, has been built. A preliminary liquid hydrogen temperature test demonstrated the need for more adequate radiation shielding, which is being installed.

72-Inch Chamber

The 72-inch chamber design is proceeding. The vacuum-vessel design has been completed and the contract let for fabrication. The magnet design is complete except for a few small details. The liquid hydrogen storage dewar is being fabricated. The refrigeration and expansion systems are under design, as is the chamber proper. The decision to use glass for the window and to use a one-window chamber has been frozen. At present "retrodirective" bright-field illumination based on a "scotch-light mirror" is thought to be a satisfactory solution to the illumination problem.

Photographic Analysis

Bubble-chamber photographs differ from cloud-chamber pictures by having greater multiple Coulomb scatter, generally smaller "droplet count," and frequently more severe turbulence.

Index of refraction of the medium in which the bubbles occur is 1.09, so that conventional cloud-chamber reprojection methods need to be modified. Considerations of speed, optical distortion, and camera aberrations led us to decide on a system of track analysis by means of electronic digital computer.

Coordinates of track segments in each stereo view are measured by the projection microscope, and are punched into IBM cards. A conventional binocular microscope has been modified for reading track

coordinates from the 35mm stereo films. The design and assembly of a faster track-coordinate measuring apparatus is under way. This faster device will use projection optics in the manner of an optical comparator to project an enlarged image onto a translucent screen. Moving the film stage by means of precision screws will permit alignment of the image with cross hairs for measurement. Devices for converting shaft position to digital data have been ordered. They will automatically translate the track coordinates into signals suitable for operation of an IBM card punch, which is on hand.

An IBM type 650 machine has been programmed to compute momentum components from the coordinates and the known magnetic field in the chamber. Provision is made in the program to correct for nonuniform magnetic field, and for optical distortions and aberrations by comparison with a three-dimensional grid of accurately known location.

REPORT ISSUED

"The Ratios of Lifetimes of Heavy Mesons and Hyperons as Predicted by Phase Space," by M. Lynn Stevenson, has been issued as UCRL-3275. It discusses products of such reactions as

$$\tau \rightarrow 3\pi,$$

$$\Sigma \rightarrow p + \pi,$$

$$\Lambda \rightarrow p + \pi,$$

and $\Xi \rightarrow \Lambda + \pi$ compared to

$\theta \rightarrow 2\pi$, and considers explanations of the observed relative decay modes, masses, and the equal lifetimes of the K mesons on the basis of various proposed schemes.

PHYSICS RESEARCH

Walter H. Barkas in charge

The following abstracts submitted for the Washington meeting of the American Physical Society summarize some recent high-energy work carried on in this group.

MASSES OF K MESONS FROM RANGES OF THEIR SECONDARIES*

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

Our recent[1] measurements have established several high-velocity points relating meson ranges in emulsion and their momenta. The measured ranges agree with the curve of Barkas and Young to about 1%, but for determining momenta of K-particle secondaries a better relation is needed. With the cooperation of Mr. James Baker a digital computer has been used to calculate a new curve. A mean ionization potential of 323 ± 11 ev was found by trial best to fit the measured points. Our τ-meson secondary ranges with the new curve lead to a Q-value of 75.08 ± 0.20 Mev. The τ-mass is, therefore, 966.3 ± 0.7 m_e; the accuracy now is limited chiefly by the uncertainty in the pion masses. Ranges of secondaries from $K_{\pi 2}$ and $K_{\mu 2}$ modes of decay have been measured by several groups.[2] From averages of all known ranges (corrected for emulsion density) we find $K_{\pi 2}$ = 962.6 ± 1.6 m_e and $K_{\mu 2}$ = 963.4 ± 2.1 m_e. Errors quoted are standard deviations arising from range straggling alone. The magnitude of the straggling is about as expected from theory. Systematic errors as follows remain: (a) errors in L-meson masses, (b) uncertainty as quoted in mean ionization potential, (c) radiative decay, (d) deficiencies in Bethe-Bloch stopping theory, (e) errors in correction for density effect.

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* Abstract for the Washington meeting of the American Physical Society, April 1956.

1 Barkas et al., Phys. Rev. 100, 1797 (1955).

2 D. M. Ritson et al., private communication (preprint); Marian N. Whitehead et al., "Properties of Positive K Mesons," UCRL-3295, Feb. 1956; J. H. Davies et al., Nuovo Cimento II N. 5, 1063 (1955); F. M. Smith et al., "Composition of a Secondary-Particle Beam from the Bevatron," UCRL-3289, Feb. 1956; L. LePrince-Ringuet et al., private communication (preprint).

ANTIPROTON MEASUREMENTS IN EMULSION*

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

We have used a stack of nuclear track emulsion to study the production and behavior of antiprotons obtained by use of the 6.2-Bev beam of the Bevatron. Magnetically analyzed negative particles of 700 Mev/c emitted from the target in the forward direction were observed. The ratio of pions to antiprotons found was $\approx 3 \pm 1 \times 10^5$. The mass calculated from range and momentum for two particles for which both the range and momentum could be determined was $1.01 \pm 0.03\ M_p$. The error indicated is statistical; an uncertainty of ~2% existed in the absolute momentum. By track opacity and residual range the mean mass also was measured to be $1.01 \pm 0.03\ M_p$. Scanning was carried out by observing the grain density of tracks entering the emulsion stack. If the first four centimeters of track is eliminated from the calculations, the mean free path based on the tracks of five definitely established antiprotons, for which two interactions in flight were observed, is 18.2 cm. If two additional events which we believe (but cannot prove) to be antiprotons are included, the mean free path is 28.7 cm. Photo-micrographs of annihilation stars will be shown and analyses of the stars made.

POLARIZATION OF BREMSSTRAHLEN*

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

The polarization of 6 ± 2 -Mev photons in the 24-Mev bremsstrahlung beam of the Stanford Mk II electron linac has been observed, and the angular dependence of the polarization has been measured. The polarization detector utilized the dependence of deuteron photodisintegration upon polarization, and consisted of D_2O-loaded Ilford C.2 emulsions placed directly in the bremsstrahlung beam. The results agree only qualitatively with the theory.[1, 2, 3] For a 1-mil-thick aluminum radiator, the preliminary values of photon polarization (May's definition) are $P(\theta_0) = 0.242 \pm 0.081$, $P(1.6\,\theta_0) = 0.157 \pm 0.095$, and $P(2.5\,\theta_0) = 0.123 \pm 0.102$. Here $\theta_0 = 1/48$. Comparison of results with the theory and with previous work[4, 5, 6, 7] will be made. The authors wish to thank the Hanson High Energy Physics Laboratory, Stanford University, for the use of and help with the accelerator.

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* Abstract for the Washington meeting of the American Physical Society, April 1956.

1 M. May and G. C. Wick, Phys. Rev. 81, 628 (1951); Michael M. May, Phys. Rev. 84, 256 (1951).

2 R. L. Gluckstern, M. H. Hull, Jr., and G. Breit, Phys. Rev. 90,1026 (1953); R. L. Gluckstern and M. H. Hull, Jr., Phys. Rev. 90, 1030 (1953).

3 Robert Karplus and Alfred Reifman, "Polarization of Bremsstrahlung," UCRL-2686, Sept. 1954.

4 K. Phillips, Phil. Mag. 44, 169 (1953).

5 E. G. Muirhead and K. B. Mather, Australian Journal of Physics 7, 527 (1954).

6 Christophe Tzara, Compt. rend. 239, 44 (1954).

7 J. W. Motz, Bull. Am. Phys. Soc. II, 1, No. 1, Abstract AB8 (1956).

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

(Thesis Abstract)

Evan Bailey

The differential cross sections for the production of hydrogen and helium isotopes in the 190-Mev proton bombardment of C, Al, Ni, Ag and Au and in the 205-Mev alpha-particle bombardment of Al and Ag are presented. The secondaries were detected in nuclear track plates located inside the 184-inch synchrocyclotron tank, and were identified through their curvature in the cyclotron's magnetic field, their range in emulsion, and their gap or grain density. Absolute cross sections were determined by measuring the target's activity, and by comparing it with the activity of a target calibrated in the external cyclotron beam. Approximately 4000 secondaries were analyzed for each bombardment. The results indicate (a) low-energy protons and alpha particles are produced in the evaporation process, (b) deuterons, tritons, He^3, high-energy protons, and high-energy alpha particles are produced in fast (cascade, pickup, knock-out) processes, and (c) the evaporating nucleus has a center-of-mass motion. The number of evaporation protons and alpha particles per nuclear collision, the effective height of the Coulomb barrier of the evaporating nucleus, and the average excitation energy of the evaporating nucleus are calculated. The evaporation theory of Weisskopf and LeCouteur is reformulated to predict relative evaporation yields of various secondaries. The observed yields of evaporation neutrons, protons, and alpha particles from the 190-Mev proton bombardment of the listed elements agree with this theory.

THE ABSOLUTE YIELD OF LOW-ENERGY NEUTRONS FROM 190-Mev PROTON BOMBARDMENT OF C, Al, Ni, Ag, AND Au

(Thesis Abstract)

Edward Gross

The nucleons emitted from high-energy nuclear disintegrations are believed to be the result of a two-stage process: (a) the cascade process followed by (b) the evaporation process. Information concerning the roles of these two processes may be obtained from analyses of the emitted neutron spectra. To this end the differential cross sections for the production of neutrons in the energy interval 0.5 to 12 Mev were measured with C, Al, Ni, Ag, and Au targets at 45°, 90°, and 135° to the 190-Mev proton beam direction. The neutrons were detected by the technique of proton recoils in nuclear emulsions. The internal cyclotron beam was monitored by comparing the activity of foils placed over the target to the activity of foils exposed to the external cyclotron beam. The angular variation of the neutrons emitted from Ag and Au appears to be isotropic in the laboratory system. An angular variation begins to appear in the neutrons emitted from Ni and becomes more pronounced in the neutrons emitted from Al and C. Some of the angular variations are consistent with an isotropic center-of-mass distribution, but the angular behavior above a neutron energy of 3 Mev cannot be so interpreted. The observed spectra are therefore attributed to two processes: (a) an isotropic evaporation process, and (b) an angle-dependent

cascade process. The total cross section consistent with center-of-mass isotropy is plotted against mass number and compared to similar results from 14-Mev neutron bombardment. The average excitation energy of the evaporating nucleus is plotted against mass number of the target and compared to excitation energies calculated by the Monte Carlo method.

In other work, progress has been made as follows.

INTERACTIONS OF 5.7-Bev PROTONS IN EMULSION

P. C. Giles

Research is continuing on the interactions of 5.7-Bev protons in nuclear track emulsion. In addition to inelastic interactions with large nuclei, and elastic and inelastic interactions with free protons, a diffraction scattering phenomenon is observed. This scattering is interpreted as being a contribution to the scattering by the nucleus as a whole; i.e., some coherent scattering by the nucleons that comprise a nucleus. The mean scattering angle of this type of event is $\sim 1^{\circ}$.

RESEARCH WITH THE SPIRAL-ORBIT SPECTROMETER

A. Photomeson Production Ratio from Deuterium at 12 Mev

Walter F. Dudziak and James Vedder

An experiment was made to measure at low meson energy (12 Mev) and at 90° to a photon beam the π^-/π^+ ratio from deuterium, by use of a counter technique. A few years ago a similar attempt was made using a nuclear emulsion method. Because a CD_2-C subtraction technique was used to obtain this ratio, it was found that even with the advantage of large-solid- angle focusing of a spiral-orbit spectrometer, the task of establishing an accurate ratio with emulsions would be very difficult because of the many hours of scanning that would be necessary. Although the task of scanning is eliminated by substituting a counter technique for the solution of the problem, many new difficulties are introduced in addition to the normal problems that confront all counter synchrotron experiments. Some of these will be mentioned. To measure a ratio at 12 Mev requires thin CD_2 and C targets. The target thickness was chosen so that a mean meson energy loss in the target was 2 Mev. The resulting 10-Mev mesons were focused by the spiral-orbit principle and detected by double coincidence. At this energy the π^- and π^+ are counted at the same time, thus minimizing the photon beam-monitoring error. Since the projected range of a 10-Mev meson in plastic scintillator is approximately 5.5 mm, the thickness of the first plastic crystal was chosen as 2 mm. Because of this, a high-gain system was necessary in order to convert the scintillations in such a crystal into a measurable electronic pulse. Hence, in addition to mesons, our system was sensitive to electrons, 47-megacycle rf pickup, and pulses associated with the synchrotron magnet commutator. We were successful in eliminating counts contributed by the last two sources on employing additional shielding of the phototube high-voltage and signal-output cables and using rf filter traps. However, we were not able to increase our signal-to-noise ratio to much greater than one at this low meson energy. During the experiment an additional carbon target was cycled with the 12-Mev CD_2 and C targets. This additional target was used as a source of 35-Mev mesons and served

as a standard as well as a source of mesons for determining the counter detection efficiencies. The 35-Mev mesons were degraded to 10 Mev by a hollow Cu cylindrical degrader and measured with the double-coincidence system. To establish the correction for counter detection efficiency, an absolute measure was made of the π^-/π^+ ratio from carbon at 35 Mev. This was possible by increasing the magnetic field so that 35-Mev mesons were focused by the spectrometer and detected by quadruple coincidence. Since the mesons did not stop in the counters and the same magnetic and counter geometry was used for the different charged mesons, the detection efficiency for both charges was the same. We are now reducing our data, from which a π^-/π^+ ratio for deuterium at 12 Mev will be obtained.

B. Photomeson Production Ratio from Complex Nuclei at 35 Mev

Walter Dudziak, James Vedder, and Norris Nickols

With a quadruple-coincidence counting technique mentioned above and the 40-inch spiral-orbit spectrometer, we are studying the behavior of photomeson production as well as the π^-/π^+ ratio from complex nuclei at a meson energy of 35 Mev. The experiment is now in progress and is being conducted simultaneously with photomeson experiments by Imhof et al. At this time we have no significant results to report.

REPORT ISSUED

A paper entitled "Mass and Spin-Parity Character of the Tau Meson," by Harry H. Heckman, Frances M. Smith, and Walter H. Barkas, has been issued as UCRL-3291. It presents analyses of 41 τ- and τ'-meson decay events.

THEORETICAL GROUP

David L. Judd

The dispersion relations derived by Goldberger (Phys. Rev. 99, 979 (1955)) for pion-nucleon scattering have been extended to the case of fixed, finite momentum transfer. The derivation has been facilitated by use of the special Lorentz frame, in which the sum of the momenta of the initial and final nucleons is zero. In this reference system the relations between dispersive and absorptive parts of the scattering amplitude are independent of momentum transfer, and are similar in form to the zero-momentum-transfer relation of Goldberger. At energies below the minimum energy necessary to allow a particular momentum transfer the scattering amplitude has no direct physical meaning, and is interpreted as an analytic continuation of the physical amplitude to scattering angles corresponding to $\cos\theta < -1$. The results are expressed in terms of the amplitudes for individual angular momenta. This work has been done in collaboration with Professor Gyo Takeda, now at Brookhaven National Laboratory. (Richard Capps)

The diagonalization of matrices arising in the solution of a nucleon in a spheroidal potential with spin-orbit coupling is now being carried out. (Marvin Rich)

An examination of the Goldhaver model for hyperons was undertaken at the suggestion of Dr. Edward Teller. Although no definite conclusions as to its validity can be made at this time, certain properties of K particles are necessary for it to be valid, viz., (1) the K^-N interaction must be strongly attractive, (2) the K^+N system does not bind, (3) the K^-K^- interaction even at close distances must be negligible, and (4) the nucleon-nucleon interaction must be quite strongly velocity-dependent to yield agreement with the hyperfragment data. A phenomenological fit of these requirements in terms of scalar and vector potentials appears to disagree with the available K^+ scattering data. (Stephen Gasiorowicz)

An unsuccessful attempt was made to express the Feynman variational principle for path integrals (Phys. Rev. 97, 660 (1955) in more conventional terms. It was attempted to use the fact that

$$\lim_{u \to \infty} \left\langle e^{-uH} \right\rangle \sim e^{-uE_o} \geq e^{-u\langle H \rangle},$$

which does yield the usual Rayleigh-Ritz principle. The hamiltonian obtained after the elimination of the oscillators, however, was too complicated to be managed by methods other than a path integral expression. (Stephen Gasiorowicz)

Calculations of the predictions of the Lepore-Neuman statistical theory for multiple pion production, antiproton annihilation, and associated strange-particle production are nearing completion, and should be ready for publication shortly. Possible modifications of the theory, together with methods for including conservation of angular momentum, are being studied. One method has been found which shows promise in the latter respect. (Dan H. Holland)

The calculation of cross sections for production of strange particles is being continued. It has been extended to include scattering of K-mesons from protons. (Richard Spitzer)

A letter entitled "Radiative and Nonradiative Boson Decay into Leptons" (written in collaboration with Malvin A. Ruderman) has been submitted to the Physical Review. This work was reported on at the New York meeting of the American Physical Society. (Sidney A. Bludman)

A note on the "Interpretation of K-Meson Decays" has been written up as a University of California Radiation Laboratory Report No. UCRL-3271. (Sidney A. Bludman)

The calculation of meson production in meson-nucleon collisions has been carried through. Use has been made of the Chew-Low scattering amplitude off the energy shell in the intermediate state. This amplitude exhibits explicitly the resonance behavior of the isotopic spin 3/2, angular momentum 3/2 scattering state and leads to a measurable cross section for the process $\pi^+ + p \rightarrow 2\pi^+ + n$ in the medium energy range. The angular distribution of pions is of the form $A + B \cos^2 \theta$, which agrees with the covariant perturbation calculation of Miyachi (Prog. Theor. Phys. 12, 2 (1954)) on $\pi^- + p \rightarrow \pi^- + \pi^+ + n$ using pseudovector coupling. Pseudoscalar coupling in perturbation theory gives a different angular distribution (backward maximum). Therefore an experiment at an energy of about 400 Mev looking for the production of an additional meson and its angular distribution may be of use for clarifying the coupling scheme. Another interesting point is that interference effects between the two outgoing mesons seem to greatly reduce the probability of the nucleon's flipping its spin in the process. (Saul Barshay)

The 300-Mev proton-proton scattering phase shifts obtained by Stapp and Ypsilantis from the analysis of the polarization experiments at Berkeley are being analyzed in terms of a potential-well model. As yet only s- and d- state scattering have been examined. A potential well of Yukawa form with a hard core has been found that fits the experimental s and d phase shifts. For the value of the hard-core radius used (0.6×10^{-13} cm), this Yukawa well is much deeper and narrower than that which fits the low-energy scattering data. This result indicates that a smaller hard core ($\sim 0.4 \times 10^{-13}$ cm) will yield Yukawa-well parameters more in agreement with the low-energy well parameters. (Al Garren and Warren Heckrotte)

Work is continuing on understanding the antiproton annihilation. A paper has been submitted to the Physical Review entitled "Selection Rules for $N\bar{N}$ Annihilation." It is emphasized that if small pion multiplicities are favored, then a pair of heavy mesons should be significant decay mode of nucleonium. Also, the probability of decay into only neutral pions is estimated. (Charles Goebel)

Interaction wave functions have been deduced for S states directly from a phase-shift analysis of the scattering data below 50 Mev. These wave functions show a remarkable consistency with those corresponding to known potential functions. In collaboration with H. P. Noyes, an extensive

computational program has been set up at Livermore, designed to deduce the shape characteristics and corresponding interaction wave functions in a number of scattering states from the data below 300 Mev. (Robert Raphael)

In collaboration with H. Feshbach (MIT), it has been found that an accurate measurement of the angular position of the Coulomb interference minimum in p-p scattering at 32 Mev will strongly restrict the shape of the S-state potential. We plan to have the necessary experiments performed on the Berkeley linear accelerator. (Robert Raphael)

PHYSICS RESEARCH

Edward J. Lofgren in Charge

TOTAL HYDROGEN CROSS SECTION FOR ANTIPROTONS

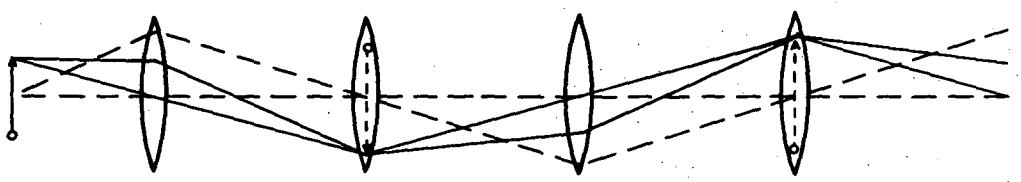
Bruce Cork, Oreste Piccioni, and William A. Wenzel

We have examined the possibility of obtaining a beam of antiprotons with an intensity of the order of 1 per Bevatron pulse. At this rate experiments like the measurement of the total cross section in hydrogen or the search for antineutrons produced by charge exchange seems feasible. For an accurate measurement for the time of flight, the particles in the beam must travel a long path while still maintained within an acceptable cross-sectional area. To reach a satisfactory solution, we contemplate the use of four available quadrupole lenses of 4-inch aperture. A distinctive feature of our optical array is the use of two additional lenses, located at the image points for particles of momentum equal to the central value of the selected momentum range. The effect of these two lenses is to maintain a good aperture of the system for a relatively extended source and a fairly large momentum spread, which is needed to achieve the maximum intensity. The sketch (Fig. 1) shows two representative trajectories along the system, omitting the deflections within the Bevatron itself and in the external magnets. The distance between the lenses is about 20 ft. We plan to place this system along the same trajectory as used by Stork, Kerth, and Birge, who furnished us with the data on the intensity of pions.

PROPOSAL FOR A COAXIAL ELECTROMAGNETIC SEPARATOR FOR PRODUCTION OF AN ENRICHED ANTIPROTON BEAM

Joseph J. Murray

Preliminary design has been started on a coaxial electromagnetic separator for production of an enriched antiproton beam. Present ideas involve an evacuated coax 55 feet long, 8-inch o.d., 2-inch i.d., with 350-kv dc between the inner and outer conductor and 6000 amperes dc flowing inside the grounded inner conductor. With this potential and current, a 1 Bev/c-proton with $\beta = 0.73$ moving approximately paraxially is undeflected by the crossed E - H field. High-energy pions, however, with $\beta \approx 1$, experience an outward force that sweeps them into the outer conductor. Plans are to use 8-inch-quadrupole focusing magnets preceding and following the coaxial separator plus an additional magnetic deflection following the last quadrupole. When the 2.5° target in the Bevatron is used, the intensity of antiprotons from this system should be ~30 times that obtained with the Chamberlain-Segrè system. This takes into account the dispersion of the source, effects of the focusing magnets, defocusing forces of the coax for proton velocities $\neq 0.73$ c, and partial interception of the beam by the center coax conductor. The momentum resolution of the system is $\pm 5\%$. Taking into account Coulomb and nuclear scattering of pions when they strike the outer conductor, an enrichment factor of ~100 is expected. It should be possible to collect the beam within a 3-inch-diameter circle of confusion in a region ~5 feet long located ~30 feet beyond the final quadrupole.



MU-11043

Fig. 1. Equivalent optical system.

K-PARTICLE PRODUCTION STUDIES

Warren W. Chupp and Sulamith Goldhaber

The emulsion stacks that were exposed at 90° to the proton beam, with the 90° magnetic focusing sector, have been partially scanned. The experimental arrangement and conditions of exposure have been described in an earlier report.[1]

At present the scanning has been carried out on stacks exposed in the 250-Mev/c momentum channel for incident proton energies of 2.6, 4.2, and 6.2 Bev.

The results obtained to date are summarized in Table I.

Table I

Results of K-particle production studies

T_{proton} (Bev)	No. K^+/cm^2 per 10^{12} protons on target	K^+/π^+
2.6	9	1/750
4.2	13	1/400
6.2	40	1/200

Normalization of the proton beam was effected through comparison of the Na^{24} activity induced in the Al monitor foils affixed to the target.[1] It should be pointed out that the ratios quoted above are observational in nature, i.e., they refer to the ratios observed at 10 feet from the target, after the particles have passed through a 0.1-inch Al window.

The comparison of the relative yields of K^+ and τ^+ mesons is straightforward, since the geometry was constant and the only parameter that varied was the proton energy.

The K^+/τ^+ ratio appears invariant with respect to bombarding energy. The value of K^+/τ^+ observed in these experiments to date is 15:1.

[1] Physics Division Quarterly, UCRL-3115

ANTIPROTON INTERACTIONS IN NUCLEAR EMULSIONS

Warren W. Chupp and Sulamith Goldhaber

A portion of one of the large emulsion stacks that were exposed in the 700-Mev/c negative-particle momentum channel* has been scanned with the following results:

1. Twenty-one cm^2 of emulsion normal to the beam direction at the incident end of the stack have been scanned for particles of approximately 2 x minimum ionization. This corresponds to a total pion flux of 3.0×10^6. Particles with this ionization and entering within $\pm 10^o$ of the beam direction in the stacks are followed.

Because no absorber other than helium and a small amount of air path was used ahead of the stacks, the angle and ionization criteria permit the selection of antiproton tracks with high efficiency.

2. All three particles found enter the stack within $\pm 0.5^o$ of the beam direction and have the correct ionization.

3. One particle (Event No. 1) interacts in flight after traveling a distance of 4 cm in the emulsion, producing a 15-prong star. The other two come to rest in the emulsion and produce energetic stars.

The events are described in Table II.

REPORT ISSUED

A paper entitled "Interactions of Antiprotons in Lead Glass" by John M. Brabant, Bruce Cork, Nahmin Horwitz, Burton J. Moyer, Joseph J. Murray, Roger Wallace, and William A. Wenzel has been issued as UCRL-3302.

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* The 700-Mev/c-momentum joint exposure was carried out by Owen Chamberlain, Warren W. Chupp, Gerson Goldhaber, Edward J. Lofgren, Emilio Segrè, and Clyde E. Wiegand.

Table II

Event	Number of prongs	Number of π's	Energy release in π(incl. $M_\pi C^2$) (Mev)	Total Visible Energy	Momentum unbalance (Mev/c)
1 (in flight) T_p=177 Mev at interaction	15	2	462	880	325
2 (at rest)	7	3 probable	analysis incomplete	----------	---------
3 (at rest)	10	4	$\geqslant$ 1200	$\geqslant$ 1295	---------
			analysis incomplete		

PHYSICS RESEARCH

Burton J. Moyer in charge

GAMMA-RAY SPECTROSCOPY OF CARBON-12 NUCLEUS

Harold E. Adelson and Charles N. Waddell

In an effort to determine the relative probabilities of radiative transition of the 15.1-Mev level in C^{12} to the ground state and the first excited state, we set up the 180° magnetic pair spectrometer at 90° to the linear accelerator proton beam. Because of space considerations, the 20-ton magnet had to be placed outside the existing secondary bombardment area and a temporary shelter was erected for the equipment.

A rather large neutron flux necessitated the construction of a concrete wall and the installation of a large water tank to shield the magnet. With judicious use of paraffin and boric acid powder it was possible to reduce the background to a sufficiently low level.

We successfully observed the 10.7-Mev gamma ray corresponding to the transition from the 15.1-Mev level to the 4.43-Mev first excited state of carbon. During the course of the experiment the gamma-ray spectrum from approximately 4 Mev to 17 Mev was examined. In addition to the expected 4.43-, 10.7-, and 15.1- Mev gamma rays, there was an indication of a gamma ray of approximately 13 Mev. There was no indication of gamma rays of energy greater than 15 Mev-- in particular, there were no gamma rays of approximately 17 Mev that would have an intensity comparable to that of the 13-Mev transition. If the 13-Mev gamma is the result of a transition to the first excited state of carbon from a higher excited state of carbon, then that state must be 0^+ or have spin greater than 2. However, because of the high bombarding energy, it is impossible to tell if this gamma is actually from the carbon nucleus.

In an effort to determine the sources of the neutron background, a neutron survey of the linear accelerator area was made in conjunction with Alan Smith of the Health Physics group. Remedial measures based on the data from this survey were devised, and an experiment is currently in progress to determine the origin of the γ ray by threshold measurements.

PHOTON SELECTOR FOR (γ, p) CROSS SECTION AT HIGH ENERGIES

Robert J. Cence

A counter is being developed to observe electrons scattered by bremsstrahlung events in the internal target of the synchrotron. These electrons are analyzed by the synchrotron magnet and hence one can place a counter so that only electrons in a certain energy interval are observed. The counter now being developed will observe 65-Mev electrons and hence will have associated photons of 275 Mev when the bremsstrahlung limit is 340 Mev. The full width at half maximum of the interval is expected to be about 30 Mev. The photon selector counts will then be put in coincidence

with the protons produced in (γ, p) reactions. Thus, one knows the energy of the photon initiating the reaction. These reactions will be studied on different elements to give a more quantitive test of the quasi-deuteron model.

SCATTERING OF PHOTONS BY PROTONS

Larry L. Higgins

In order to make a better measurement of the cross section for proton Compton scattering, work is in progress to develop a gamma-ray counter with about 100% efficiency and able to measure the energy of the scattered gamma rays. Various designs seem to indicate that an energy resolution as good as 10% may be possible. Some of the designs considered are:

1. Small heavy glass chips in liquid scintillator.

2. Small plastic scintillator balls in heavy clear liquid.

3. Liquid scintillator loaded with heavy liquid.

4. A sandwich of thin sheets of lead and plastic scintillator.

5. Heavy-liquid Cerenkov counters with wave shifter to increase light collection.

6. Chips of NaI(Tl) scintillation crystals immersed in a liquid to match index of refraction.

The size of the counter necessary to fully develop a 100-Mev shower depends on the material used, but should be about 15 by 15 by 30 inches. A conclusion as to which idea should be finally pursued has not yet been reached.

NEUTRON YIELDS AT THE LINEAR ACCELERATOR

Selig N. Kaplan and George P. Millburn

The measurement of neutron yields from 18- and 32-Mev protons bombarding thick targets has been completed and a final report is in preparation.

PHOTONIC DECAY OF HEAVY MESONS AND HYPERONS

John E. Osher and Sherwood I. Parker

To reduce the large gamma background observed in the August run on the Bevatron, the gamma-ray telescope was raised, lead collimation was was placed between it and the beam, and the uranium slits that were plunged with the target and which might have been a source of background gamma radiation were removed. The new arrangement did not use a movable target; instead, the telescope and collimator were mounted on tracks placed parallel to the beam direction, with their position controlled from the Bevatron pit by a long rod.

These changes made it possible to run behind other K-meson experiments. During such a run in December 1955 and January 1956 we concluded:

1. The background has been reduced sufficiently so that the decays of the θ^0's and Λ^0's can be clearly observed. This was tested by observing the drop in counting rate when the converter was removed or when the channel leading up to the telescope was closed with a lead block.

2. Gamma rays, observed both upstream and downstream from the target, had a spatial decay rate roughly equal to that expected from θ^0 and Λ^0 decay.

3. The gammas observed upstream from the target could only be due to the decay scheme $\theta^0 \rightarrow \pi^0 + \pi^0$, unless some undiscovered K meson, such as a possible τ^0, were to decay with a 10^{-10}-second half life.

4. The number of these charged relativistic particles (the telescope counts as well as gammas) has about the same order of magnitude as the number of gammas, indicating that charged and uncharged decays of the θ^0 are comparable in frequency.

5. The observed decay scheme then demands that the spin of the θ^0 be even, and suggests that it is zero.

ELASTIC PROTON SCATTERING

Harlan C. Shaw

A program of proton elastic scattering at 12 Mev has been begun at the 60 inch cyclotron with Homer Conzett, Rodolfo Slobodrain, and Robert Summers-Gill. Data on the angular distribution of the elastic protons have been taken at 5° intervals from 7° to 160° (laboratory system) for ten elements to date: beryllium, carbon, magnesium, aluminum, iron, copper, zinc, silver, tantalum, and platinum. Data from several more elements are being obtained currently.

Results so far show the expected oscillating interference pattern between the Coulomb and nuclear potentials, with the frequency of the oscillations increasing with the heavier elements. The amplitude of the oscillations decreases with the heavier elements as the rising Coulomb barrier makes this interaction strong.

The experimental technique utilizes a 36-inch-diameter scattering chamber with a triple proportional counter mounted near the periphery of a rotatable table. The angular relation of the counter to the target, and the amount of absorber placed in front of the counter, can be controlled remotely. An integral method of counting is used wherein sufficient absorber is placed in front of the counter to separate inelastic protons from excited levels from the elastic group, and the discriminator biases on the proportional counter pulses are then set just below the group of pulses corresponding to the elastically scattered protons. The proton beam level is monitored in a Faraday cup.

It is planned to present these data, when completed, for theoretical analysis on the basis of the optical model.

LINEAR ACCELERATOR INSTRUMENTATION

Robert K. Squire

A neutron spectroscope has been designed to work in the range 10 to 30 Mev. The neutron detection is accomplished by a n-p collision in a plastic scintillator; the neutron energy is measured by proton-recoil pulse-height analysis of those collisions for which the neutron is left with a given momentum vector; and a subsequent neutron detection is made in a second large annular counter.

The calculated efficiency is of the order of 10^{-4} and the resolution 15%. Assembly is expected in about a month.

EXPERIMENT TO MEASURE POSITIVE PION CROSS SECTIONS AT HIGH ENERGIES

N. Fredrick Wikner and Hoyt A. Bostick

In early November the apparatus used for measuring negative pion cross sections was arranged inside the Bevatron magnet in an attempt to measure positive pion cross sections at Bev energies. It was found that the existing system was unsuitable for the following reasons:

a. Stray magnetic fields from the Bevatron strongly affected the relatively lightly shielded photomultiplier tubes within about 15 feet of the machine.

b. Accidental counting rates were far in excess of tolerable levels, owing to a high background flux.

During November and December new Cerenkov counters with adequate magnetic shielding were designed and built. A second bending magnet bringing the pion beam out nearly along a Bevatron radius was introduced in order to minimize the stray field along the counter array. Uranium and lead collimation before the steering magnets, together with many concrete blocks installed on the platform, reduced the background flux to the point where accidentals were negligible. With these modifications it was determined that reliable particle detection was possible inside the Bevatron ring. Operating conditions on the machine were changed before any data could be taken, so the experiment will be continued at a later date.

CLOUD CHAMBER STUDIES

Wilson M. Powell in charge

Experiments

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

One of the heavy-meson production events was known to contain the production and decay of a θ^0 meson. A complete analysis using energy and momentum conservation yielded the interesting result that the missing neutral particle was ~500 Mev. mass. The nucleonic mass of the struck proton was contained in a positive prong leaving the initial scattering. It had been thought that this prong was probably a Σ^+ and that this event showed the associated production of a Σ^+ and a θ^0. The calculations using the conservation laws showed that this interpretation was exceedingly unlikely and probably could be ruled out. The event would have to be interpreted as a violation of associated production or the simultaneous production of a θ^0 and a K^0. Considerable effort was expended in considering all other interpretations that could be thought of and in evaluating their probabilities. For this purpose the IBM650 program that had become operative was used to good advantage.

The analysis is practically complete and it is expected that a report will be issued in the first part of the next quarter.

n-p INTERACTIONS

Neutrons Emitted at 0° from 6.2-Bev p-Cu Collisions

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

Since the establishment of the production at the Bevatron of anti-protons a search is being made for evidence of antineutrons in the neutron pictures. This exposure was made at full machine energy and at 0° to the target, therefore if antineutrons are produced in the target a small number should be traversing the chamber in these pictures. An antineutron interacting with the hydrogen of the diffusion chamber has three choices:

(a) it could elastically scatter,

(b) it could charge exchange scatter,

(c) it could annihilate.

In (a), all that one would see would be a single proton recoil, and no discrimination between neutrons and antineutrons would be possible. In (c), an identification is possible since in the center-of-mass system ~2 Bev of energy is given up by the annihilation. The difficulty seems to be in the neutral particles, which would not be seen, and therefore the annihilation might be mistaken for meson production by neutrons. The emulsion stars seen so far indicate that considerable energy is indeed very often taken up by the neutral particles, and therefore an annihilation of an antineutron that is identifiable may be very rare. The reaction for (b) is

$$n^* + p \rightarrow p^- + p + \pi^+.$$

It can be argued that if the collision is highly inelastic then the antineutron will very likely annihilate, while if the collision is weakly inelastic then the antineutron may be emitted as an antiproton. This type of reaction would therefore show small momentum transfer, which means that the antiproton would make a small angle with the incoming neutron direction.

Definite identification is possible in some cases from kinematics, since the incoming momentum is limited to the maximum momentum available from the Bevatron.

5.3-Bev p-p INTERACTIONS

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

Further analysis of the 40 events obtained in the exploratory run on 5.3-Bev p-p interactions gives for the total cross section 33.3 mb±6 mb standard error. The hyperon-production event in which two positive outgoing tracks and a Λ^0 were observed is interpreted as

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

where the unseen θ^0 is inferred from the kinematics and the rule of associated production. The Λ^0 has an angle of 39° between its production and decay planes, and in decay the proton is emitted backwards at an angle of 170° in the rest frame. An additional Bevatron run is scheduled for the next quarter.

Expansion Chamber

θ_2 EXPERIMENT

John Elliott, William B. Fowler, Richard Lander,
Larry Oswald, and Wilson Powell

A cloud chamber experiment similar to the one designed by Pais and Piccioni was undertaken to detect the existence of the postulated ν_2. A beam of 1-Bev π^- mesons produced in a 1-inch Cu cube located azimuthally at 5° in the 6.2-Bev circulating proton beam of the Bevatron was focused through two sets of quadrupole magnets into a 4-by-4-by-11-inch block of Al. Neutral particles produced at an angle of about 16° to the π beam traveled 170 inches to the cloud chamber. Between the cloud chamber and the Al a pulsed strong magnetic field followed by a 3-foot steel-and-lead collimator removed most of the charged particles from the beam entering

the cloud chamber. The cloud chamber was an expansion-type chamber containing five Pb plates 5/8 by 2.5 by 19 inches, and was operated in a pulsed 21-kilogauss magnetic field.

One thousand pictures have been obtained to date. Scanning of the pictures and analysis are now in progress.

$\bar{p}$ EXPERIMENT

John Elliott, William B. Fowler, Richard Lander, Larry Oswald, and Wilson Powell

During this quarter, three thousand pictures were taken in an attempt to see antiproton interaction in the five Pb plates of the magnet expansion chamber. The run was in the separated beam set up by the Richman group. As for the emulsion exposure, the high interaction cross section of antiprotons in Be (the momentum loss occurred in Be) attenuated the number of antiprotons that entered the cloud chamber to the extent that no antiproton ending was observed.

Equipment and Techniques

HYDROCARBON BUBBLE CHAMBER

Larry Oswald and Wilson Powell

The bubble chamber and most of the associated equipment were completed during this quarter. The chamber is to be tested in the concrete house set up as a test facility by the hydrogen bubble chamber group. It has been decided because of safety considerations to operate the chamber for these tests remotely. For operation inside the Bevatron building, a second pressure vessel is to be placed around the existing chamber. This vessel will be provided with a pipe from the vessel to outside the building so that in case of failure in the chamber of the window the propane will be dumped outside. This should eliminate possible hazards in case of an accidental window fracture.

MACHINE ANALYSIS

Howard White and the Cloud Chamber Group

The program for the computation of cloud chamber scattering events, using the IBM650 computor at Livermore, became functional during the latter part of December. Data processing has begun and it is expected that information concerning the various fundamental nuclear interactions that we are investigating will be available in the near future.

STRANGE-PARTICLE DECAY CURVES

Howard White and the Cloud Chamber Group

For quick classification of neutral and charged V events, we have prepared a series of curves similar to curves computed at other laboratories. The dominant criterion in our case was to plot the variables that we observe with the best accuracy. The other parameters can then be checked for consistency within the errors of measurement. The momenta of the prongs have been computed up to 6 Bev in the laboratory system. The computations were done on the IBM650 at Livermore. Final plots are to be published in a UCRL report.

PHYSICS RESEARCH

Chaim Richman's Group

Analysis of data from a large emulsion stack is the subject of a brief separate paper, "preliminary Report on Masses, Decay Modes, Abundances, and Energy Spectra of K^+ Mesons," by Marian N. Whitehead, Donald H. Stork, James R. Peterson, Donald H. Perkins, and Robert W. Birge, UCRL-3295, March 1, 1956.

The analysis of the decay configurations of 100 τ mesons has been reported in a paper by Roy P. Haddock, "Analysis of One Hundred Bevatron τ^+ Particles," UCRL-3284, February 8, 1956.

ANTIPROTON STUDIES

The antiproton experiment described in the previous progress report was run on the Bevatron early in November. The setup employed was designed to partially separate the pion and antiproton fluxes, allowing a more intense exposure than was previously possible. The separation was accomplished by placing a beryllium attenuator between two momentum-selecting magnets. For a beryllium attenuation cross section of twice nuclear area approximately 150 antiprotons were expected in the nuclear emulsion stack exposed. To date 20% of the stack has been scanned and none have been found. This is very probably because of the unexpectedly large attenuation cross section (as subsequently measured in counter experiments).

The results of this group's participation in the cooperative exposure of stacks in the 700-Mev/c beam of antiprotons are as follows:

The plates were scanned along the front edge for twice-minimum tracks lying in a very small angular region (about $\pm 2^o$) parallel to the pion flux. Eight tracks satisfying these criteria were followed. Five particles made annihilation stars, of which four were in flight and one at rest. Of the remaining three, two left the stack and one was a K^-, making a star at rest.

One of the annihilation stars had no visible pions and only 50 Mev visible energy release.

PHYSICS RESEARCH

Emilio Segrè in charge

p-p COLLISIONS

No experiments have been performed, but the analysis for phase shifts of all data collected by our group has been pursued with the help of Henry Stapp and N. Metropolis at Los Alamos.

As of now the best sets of phase shifts are as follows:

Solution	$^1S_0$	$^1D_2$	$^3P_0$	$^3P_1$	$^3P_2$	E_2	$^3F_2$	$^3F_3$	$^3F_4$
I	-10.9°	14.2°	-3.4°	-19.1°	23.3°	-4.3°	-1.0°	-1.4°	2.1°
II	-19.5°	5.3°	-35.4°	-11.1°	23.1°	23.1°	-3.0°	1.4°	5.1°
III	-9.7°	13.4°	12.8°	26.4°	17.0°	4.5°	2.1°	-3.0°	5.0°

The experimental papers are being written and we expect to have the phase-shift analysis at this energy finished in the near future.

ANTIPROTON EXPERIMENTS

Stars Produced by Antiprotons

Intensive scanning, in Rome and here, of the plates exposed at the Bevatron in the first two runs has yielded only one star. This work has been described in Phys. Rev. 101, 909 (1956).

Report Issued

A paper by Owen Chamberlain, Donald V. Keller, Emilio Segrè, Herbert M. Steiner, Clyde Wiegand, and Tom Ypsilantis, "Antiproton Interaction Cross Sections," has been issued as UCRL-3327, February 27, 1956. This discovery has affected - among other things - the further development of the photographic work (reported below).

Antiproton Beam

We are trying to improve the antiproton beam intensity by preparing a larger version of our previous apparatus. Eight-inch magnetic quadrupoles are under construction and the plans for their use have been prepared. The intensity should improve by a factor between 10 and 20 owing to the improved geometry alone.

Irradiation of Photographic Plates

Owen Chamberlain, Warren W. Chupp, A. Gösta Ekspong, Gerson Goldhaber, Edward J. Lofgren, Emilio Segrè, and Clyde Wiegand

In view of the absorption result mentioned above, a new irradiation was planned in which (a) no absorbing material preceded the stack, (b) the range of the antiprotons ended in the stack, and (c) antiprotons and mesons

were easily distinguishable by grain density at the entrance of the stack. In order to achieve these three results it was necessary to select antiprotons of lower momentum, even if these should be admixed with a larger number of π^- than at higher momenta.

In the irradiation we exposed a stack in the same beam used previously, adjusted for 700 Mev/c momentum instead of 1090 Mev/c. Since the previous work had indicated that the most troublesome background was due to ordinary protons, the particles were also passed through a magnetic clearing field just prior to their entrance into the emulsion stacks. The clearing magnet (M_c) had B = 9900 gauss, circular pole faces of 76 cm diameter and a gap of 18 cm, so that particles scattered from the pole faces of the clearing magnet could be ignored on the basis of their large dip angles in the emulsions. With this arrangement we have achieved conditions in which the negative particles enter the emulsions at a well-defined angle, and extremely few positive particles enter the emulsions within the same range of angles. For the first time we have obtained an exposure in which more antiprotons than protons enter the stacks with the proper entrance angles. Under these conditions it is relatively easy to find antiprotons in these stacks, even though approximately 5×10^5 negative π mesons at minimum ionization accompany one antiproton. The exposure arrangement is shown in Fig. 2. The beam collimation was such that at any given position at the leading edge of the stacks the angular half width of the pion entrance angles is less than $\pm 1^\circ$, both in dip and in the plane of the emulsions. This very small angular spread allowed us to apply strict angular criteria for picking up antiproton tracks, and thus helped to reduce confusing background tracks to a negligible level. The antiproton tracks were picked up at the leading edge of the emulsions on the basis of a grain count (~twice minimum) and angular criteria ($\pm 5^\circ$), and were then followed along the track. The stacks irradiated with this technique have been distributed to groups working with:Segrè, Lofgren, Barkas, and Richman in Berkeley, and Amaldi in Rome. The scanning has proved relatively easy, and at this writing 20 antiprotons have been found. Their stars are being analyzed by the various groups and it is planned to have a comprehensive paper reviewing the results.

However, one star found by A. G. Ekspong is worth mentioning because the visible energy released is $>Mc^2$ and thus shows conclusively that the particles previously recognized as antiprotons fulfill also the requirement of liberating an energy larger than their rest mass, a fact that can be explained only by annihilation of a particle - antiparticle pair.

This work is reported in a paper submitted to the Physical Review by these authors under the title, "Example of an Antiproton-Nucleon Annihilation."

Antiproton Hydrogen Absorption

A large styrofoam target necessary for this experiment is under construction.

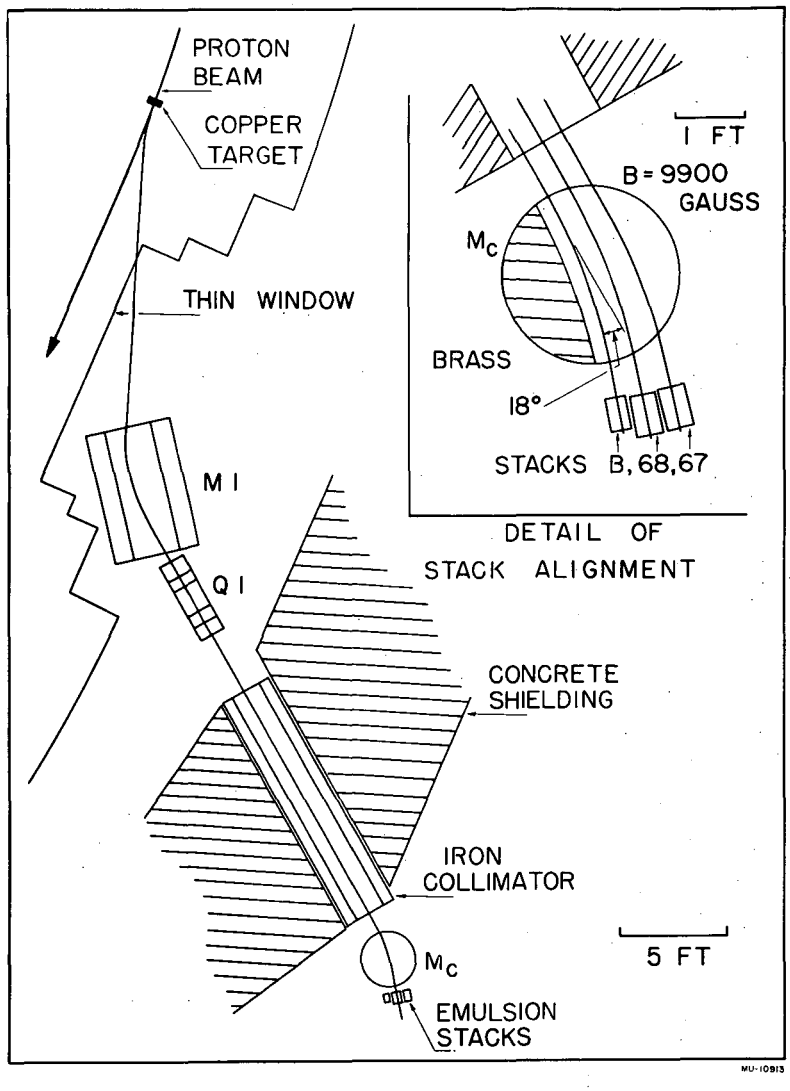

Fig. 2. Plan of the irradiation.

ANTINEUTRON EXPERIMENT

We are preparing a large multilayer detector in order to detect electronically stars produced by nucleon-antinucleon annihilation. The apparatus consists of a block 24-by- 24 by- 24-inch layers of lead and scintillating plastic (thickness 0.090 inch and 0.25 inch respectively). Showers produced by annihilation π^0, charged-particle ionization, and also nucleonic cascades, should give recognizable pulses. The fundamental units have been tested and the whole apparatus is under construction.

ACCELERATOR OPERATION AND DEVELOPMENT

BEVATRON

Edward J. Lofgren in charge

Further progress in the Bevatron program is the subject of a separate report by Walter D. Hartsough, "Bevatron Operation and Development. VII," UCRL-3236, December 16, 1955.

184-INCH CYCLOTRON

Robert L. Thornton in charge

MODIFICATION

Richard Burleigh

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

1. Drilling of upper-pole disc stack (including repairs to poor threads).
2. Sandblasting and "glyping" of spark-damaged area on upper main coil.
3. Replacement of part of main coil maple insulation with bakelite.
4. Installation of new lower main coil strongbacks.
5. Rework of lower main coil tank.
6. Installation of new lower main coil terminal box.
7. Reinstallation of upper and lower main coil tanks.
8. Rework of upper pole-base holes.
9. Relocation of mechanical vacuum pumps valve manifold.
10. Sandblasting and painting of dee tank.
11. Sandblasting and painting of auxiliary coil tanks.
12. Rework of lower vacuum-barrier disc to repair potential leaks.
13. Replacement of outer dee tank corner beam with inside beam to improve access to lower-coil terminal box.
14. Nitriding and straightening of new vibrating blades.
15. Experimental movable panels for radiofrequency tests.
16. Temporary movable stators for radiofrequency tests.
17. Dee tank access door and cover for port No. 7.

Work is in progress on the following items:

1. Meson cave slot shielding (eight-foot wheel).
2. Seal weld on lower main coil tank.

3. Installation of auxiliary coil clamp band drains.
4. Preparations for reinstallation of dee tank.
5. Assembly of pole-tip "packages" (auxiliary coils and pole-tip discs).
6. Miscellaneous plumbing.
7. Miscellaneous electrical installation.
8. Radiofrequency testing.
9. Drilling of poles for auxiliary coil supports.
10. Copper-plating new vibrating blades.
11. Design of final movable panels.
12. Preliminary design of deflector system.
13. Design of meson cave slot shielding handling gear.

60-INCH CYCLOTRON

Joseph G. Hamilton in charge

DEVELOPMENT

Control Valve Design

William B. Jones

Operational characteristics of the 60-inch cyclotron ion source have demonstrated the need for a specialized control valve. Specifications for such a valve should include the following:

(a) Vacuum tightness when the valve is in the closed position.

(b) Opening and closing without seat-to-stem adhesion.

(c) Control of gas flow for a variety of gases.

(d) Continued long-term operational stability.

(e) Construction materials with low absorption qualities.

(f) Simple, rugged construction.

For some time an attempt was made to meet these specifications with needle-type valves of more or less standard varieties. Most have been found deficient, namely in (b), (c), and (d); (b) and (d) seemed to have been related.

The design of a control valve was undertaken based upon the conductance of a gas through an annular space of variable length. This was accomplished by reaming and honing a thick-wall stainless steel tube of 9/32-inch i.d. A brass plug 3 inches long was lapped into the tube to provide an annular space of the order of 0.001 inch. Checks of the flow through this system, with 10 pounds head pressure, were within the range of ion-source requirements.

The conductance through an annular system is given by

$$\text{conductance} = \frac{12.1\ K\ (D_1 - D_2)^2\ (D_1 - D_2)^*}{L} \text{ . (liters per second)}$$

The constants chosen for the system now in use are

$D_1 = 0.283$ inch $= 0.719$ cm; $L = 7.6$ cm;

$D_2 = 0.282$ inch $= 0.7154$ cm; $K = 2$.

Thus, the calculated conductance is 1.21 cc per minute with the plunger fully inserted. Use with various gases in the cyclotron tank vacuum (2×10^{-5} mm) corroborates this.

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* "Vacuum Equipment and Techniques," Gutherie and Wakerling, p 37-38.

Most of the original specifications seemed to have been answered by this control valve, although reproducibility over a long time period has not been checked. The mechanical details of the construction and remote motivating equipment are explained below.

Valve Construction

Charles A. Corum

The valve described above was made in short concentric sections for ease of fabrication and assembly and is held together by set screws. All parts were made of stainless steel and (or) brass. The valve body and plunger (See Fig. 1) were mated according to the American Standard Medium Fit tolerances chart. Set screws hold the plunger loosely in the stem to avoid any binding due to any manufacturing misalignments. An "O" ring around the plunger and recessed into the stem shuts off the gas when the valve is closed. "O" rings seal the gas chamber, allowing for the movement of the plunger stem, which is activated by a left-hand-threaded screw. The stem is kept from rotating by two keys sliding in slots at 180° in the screw chamber tube. This was necessary to keep the screw of a nonrising nature.

The valve is mounted horizontally through the filament house wall and is operated by a flexible-shaft drive from a selsyn motor activated by a selsyn drive on the control desk.

OPERATION

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

Alpha bombardments	466.0 hr
Deuteron bombardments	136.1 hr
Proton bombardments	278.5 hr
Beryllium bombardments	31.8 hr
Experimental bombardments	87.3 hr
Operational total	999.7 hr
Outage time	139.9 hr
Available time	1139.6 hr
Shutdown	956.4 hr
Holidays	112.0 hr
	2208.0 hr

An operating efficiency of 87.7% was maintained throughout this quarterly period. Beam levels, obtained with alpha particles, were approximately 50 μa for 95 kilowatts of oscillator power.

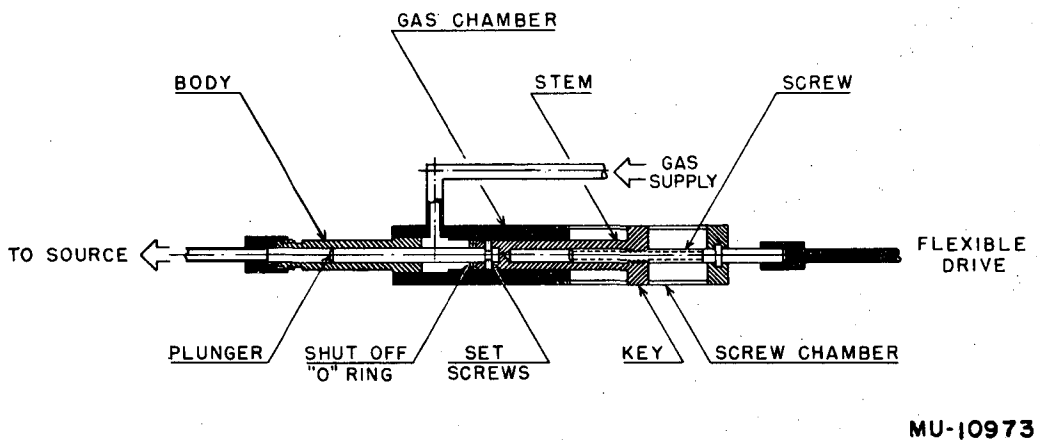

Fig. 1. Control valve for ion source for 60-inch cyclotron

LINEAR ACCELERATOR

James Donald Gow in charge

The linear accelerator operated for a total of 865 hours of research bombardment time during November, December, and January. The experiments receiving the largest share of this time were: energy levels in B^9 (Knowles), high-energy gamma radiation from light nuclei (Waddell), total neutron yields (Millburn), and inelastic proton scattering on lithium (Silver). Other work in progress included polarization experiments, β-ray spectroscopy of short-period activities, and p, n cross-section measurements.

The B^9 energy-level experiment has proven very sensitive to small drifts in the energy of the 32-Mev beam. As a result, some experiments to determine the effect of changes in the accelerator operating conditions on beam energy were made. It was demonstrated that a ± 50-kev change in the 4-Mev injection energy produced no measurable change in the 32-Mev beam energy.

A change in the radiofrequency voltage from beam threshold to best operating value ($\Delta E = 3\%$) produced a beam energy change of ~250 kev. A 0.030-inch motion of the exit end tuner produced an energy change of ~400 kev. The most serious drifts proved due to changes in cavity temperature. The energy drift from a cold start to equilibrium temperature (over a period of ~15 minutes) can be as much as 700 kev. The basic energy spread of the machine has been proven, by examination of elastically scattered protons with range-selective counters, to be less than 150 kev full width at half maximum.

As a result of the above measurements, a simple energy-regulation scheme is being designed that will use a servo loop circuit to control a small tuner in the cavity.

The program of oscillator circuit improvement, coupled with some changes in the inner filament structure of the 3 W 10.000 tube, has begun to pay dividends in terms of oscillator tube life. The average oscillator tube life is now more than 1400 hours.

No major changes in either the Van de Graaff or the linear accelerator are planned.

SYNCHROTRON

Edwin M. McMillan in charge

RESEARCH PROGRAM

Robert W. Kenney

During the period from November 1955 through January 1956 the synchrotron ran very well.

Walter Dudziak and James Vedder accumulated a great deal of data on the π^-/π^+ ratio for deuterium at 90° and for very low-energy pions. Some data have also been obtained on the Z dependence of the π^-/π^+ ratio at 90°. The data have not yet been analyzed.

William Imhoff, Victor Perez-Mendez, and Edward Knapp have obtained additional data on the Z dependence of π^+ photoproduction at 135° (lab) and at both 21 Mev and 16.5 Mev pion energy. A preliminary analysis of the data, uncorrected for Coulomb effects, yields a value of approximately 1 r_0 for the pion mean free path in nuclear matter at small pion energies. Analysis of the data is still in progress and further results bearing upon the surface production model will be reported shortly.

John Anderson and Robert Kenney have observed the A dependence of the π^0 photoproduction at 135° (lab) and for approximately 60 Mev pion energy. The apparent mean free path of 60-Mev neutral pions in nuclear matter is shown to be approximately 1.5 r_0. Further work at lower pion energy and with improved energy resolution is in progress in order to gain information, independent of Coulomb effects, bearing upon the surface production model.

On January 31, the synchrotron was shut down during the day shift to complete the installation of the capacitor bank high-voltage regulator. Tests of the completed installation will begin during February. It is expected that machine operation will be greatly improved by the elimination of effects due to variations in line voltage.

OPERATION

Rudin M. Johnson

The synchrotron has been operating at full energy for physics research experiments during this period. The beam intensity has run high and fairly steady. Some instability developed at the rf accelerating gap owing to loading caused by dirty surfaces. Normal operation was achieved by cleaning the gap (in place) with a small dental sandblaster. The upper coils were tightened and some vacuum leaks repaired at this time.

The synchrotron voltage regulator has been installed and is being tested.

The synchrotron linac Model II has been essentially completed and is undergoing debugging procedures. The linac will be ready for test runs in February.

The 2-Mev accelerator magnetron pulse transformer is being rewound for operation of the new klystron to be delivered in February.