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Unclassified Physics

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PHYSICS DIVISION QUARTERLY REPORT

August, September, October 1954

December 13, 1954

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PHYSICS DIVISION QUARTERLY REPORT

August, September, October 1954

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PHYSICS DIVISION QUARTERLY REPORT

August, September, October 1954

Radiation Laboratory, Department of Physics
University of California, Berkeley, California

December 13, 1954

GENERAL PHYSICS RESEARCH

MESON RESEARCH WITH THE SPIRAL-ORBIT SPECTROMETER

Ryokichi Sagane, Walter F. Dudziak, and James Vedder

Pion Production Using a Proton Beam

Some nuclear emulsion data obtained in the study of charged-pion production from complex nuclei, using a 340-Mev proton beam, have been analyzed. This analysis can be summarized in a table showing the variation of the π^+/π^- production ratio with mass number. The summary is presented in Table I.

Study of The Positron Spectrum From The Decay of The μ-Meson

The disagreement in the experimental value of ρ (a constant introduced by Michel into the theory of μ-meson decay), as has been obtained by the spiral-orbit spectrometer and the values reported by other laboratories, prompted an independent measurement of this constant with the aid of a 180° β-ray spectrometer. Figure 1 illustrates the experimental arrangement. As in the spiral-orbit experiment, the electrostatically deflected proton pulses of the 184-inch cyclotron were used to create low-energy π^+-mesons in a Be target 1 x 1 x 3 inches. The proton beam was collimated by a rectangular collimator whose horizontal dimension was 1.25 inches and whose vertical dimension was 0.75 inch. The low-energy pions created by this proton beam that were stopped in the target decayed into muons. Thus the pion-production target served as a source of positrons from the decay of the muon. The spectrum of this positron source was analyzed with a 180° focusing spectrometer. For each magnetic field setting a corresponding adjustment of the magnet position was made so that the proton beam would hit the target. To make certain that a slight shift in the proton beam -- which may occur during the adjustment from one positron energy point to another -- did not introduce an error in counting rate, an accurate check was made at one positron energy on the variation of the counting rate with displacement of proton beam. It was found that a misalignment of the proton beam by 0.25 inch could be tolerated without influencing the counting rate.

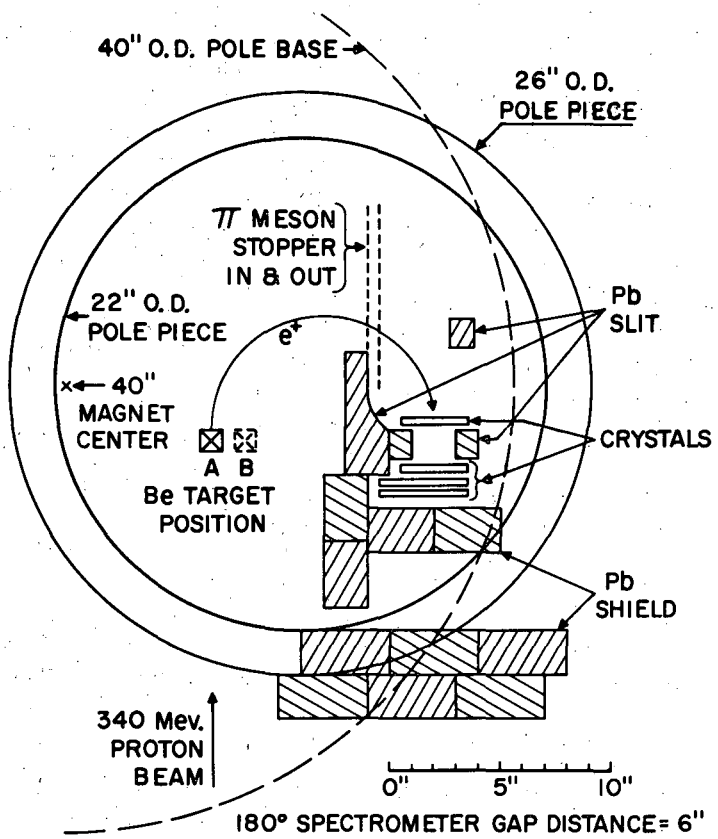
The same fast quadruple-coincidence technique as was used in the spiral-orbit spectrometer experiment was employed for detecting the positron. During this experiment two types of measurements were made,

Table I

Element	π^+/π^- Ratios at 90° to a 340-Mev Proton Beam						
	T_π=12.5±2 Mev ⊗	T_π=13±3 Mev △	T_π=18±3 Mev △	T_π=27±1.5 Mev ⊗	T_π=33±3 Mev ⊗	T_π=37±2 Mev ⊗	T_π=42±2 Mev △
Be	4.95±.53	———	5.1±0.9	6.3±1.5	———	———	———
C	4.69±.46	———	5.3±0.8	6.1± 0.6	7.8±1.5	8.4±.8	11.0±1.5
Al	2.88±.28	2.5±0.8	4.3±0.8	3.5±0.6	4.8±0.8	———	10.5±2
Cu	1.59±.18	2 ±0.4	1.95±0.5	2.65±0.4	4.1±0.6	5.6±.5	8.3±2.5
Ag	0.77±.09	0.7±0.15	1.25±0.5	2.35±0.35	4.0±0.6	———	4.8±1.5
Ta	0.47±.07	———	———	1.51±.20	———	2.46±.36	———
Pb	0.32±.05	0.47±0.1	1.2±0.6	1.8±0.35	2.3±0.3	———	4.8±2.5
U	0.32±.04	———	———	1.45±.18	———	2.13±.24	———

△ R. Sagane, Phys. Rev. 90, 1003 (1953)

⊗ New Measurements



GEOMETRY FOR 180° FOCUS MEASUREMENT

MU-8668

Fig. 1

wherein (a) the distance between the positron source and the spectrometer exit slit was kept constant and the magnetic field was varied; (b) the magnetic field was kept constant and the distance between the source and exit was varied (only two positions could be easily measured).

A preliminary analysis of the combined results is shown in Fig. 2. From this analysis a value of $\rho = 0.22^{+.06}_{-.10}$ is obtained. This value is in good agreement with the spiral-orbit data.

It should be pointed out that because of its weight, the 40-inch meson magnet could not be placed anywhere but in a small area inside the experimental cave. Because of this it was necessary to offset the smaller pole pieces in order to obtain the 180° focusing geometry illustrated in Fig. 1. As a result, at the high-energy end of the positron spectrum, a variation from uniformity of the magnetic field was observed near the crystals. In any case, the major part of the positron trajectory was in the uniform portion of the magnetic field. A correction for this nonuniformity is being made (by Mr. Norris Nickols) with an instrument designed and built by Dr. Bayard Rankin. This instrument permits mapping a continuous trajectory in a nonuniform magnetic field. The effect of the nonuniformity on the positron spectrum is not great. It adds a small tail to the resolution curve at these high positron energies.

A second 180° spectrometer experiment was undertaken using a uniform field throughout the positron spectrum. To achieve this within the limitations of the experimental cave, the light pipes connecting the crystals with the phototubes had to be increased in length from 20 to 40 inches. No useful information was obtained during this second experiment because of large fluctuations of the counting rate at each point during the experiment. A study was made to determine the cause of these fluctuations.

Studies On Electronic Fluctuations

For these studies the counting areas of Bldg. 6 and Bldg. 25 were used. Although a detailed study was made, only the briefest summary of the data obtained from the Bldg. 6 counting area is presented here. (It is felt that this summary should be useful to others using these counting areas.) A more detailed report is being made and will be submitted to Mr. Hugh Farnsworth.

For this experiment a number of good 1P21 photomultipliers were found. A good 1P21 is defined as a tube that has a good signal-to-noise ratio and for which the counting rate is reproducible over a long period of time after temperature equilibrium is established. The signal from these good photomultipliers (created by a Ra-Be source irradiating a scintillator) was fed through a standard linear amplifier and into a scaler. To test the fast quadruple-coincidence mixer, the pulse from a good photomultiplier was amplified by two HP fast amplifiers and then divided into four parts at the input to the quad mixer. The pulse from the quad mixer was fed through a standard linear amplifier into a scaler. A typical example of the fluctuations that were observed for a direct pulse and for a quad-mixer pulse before any adjustments were made is shown in Fig. 3.

It was found that the main causes of these fluctuations were: (a) gassiness of the 6AC7S tubes in the discriminator circuit of a scaler, which -- according to an experiment by Mr. W. Ganz -- are very sensitive

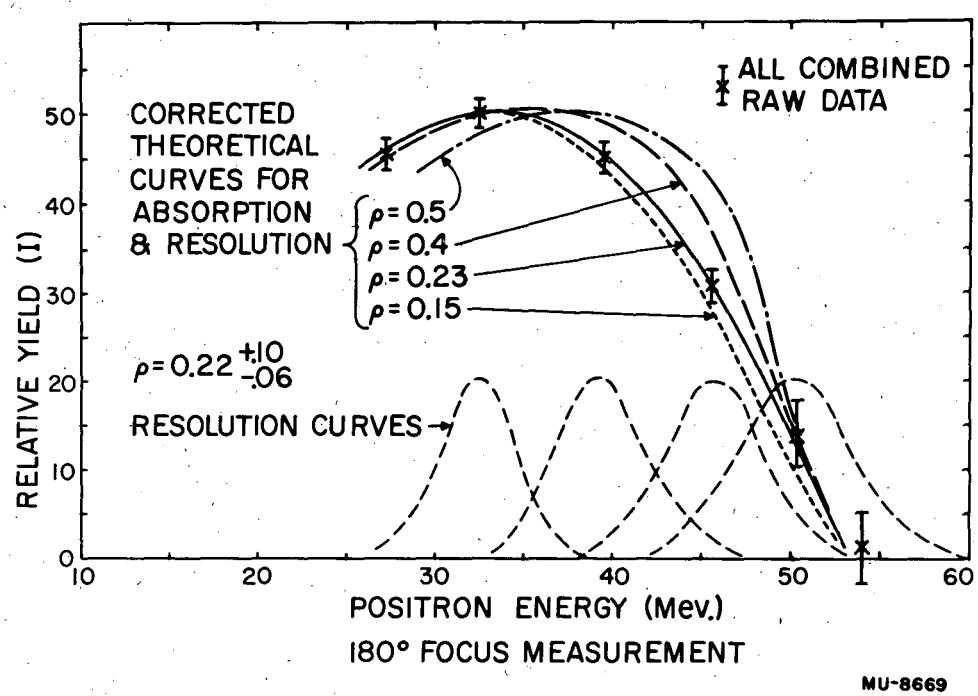

ALL COMBINED RAW DATA
CORRECTED THEORETICAL CURVES FOR ABSORPTION & RESOLUTION
ρ = 0.5
ρ = 0.4
ρ = 0.23
ρ = 0.15
ρ = 0.22 +.10 -.06
RESOLUTION CURVES
RELATIVE YIELD (I)
0
10
20
30
40
50
10
20
30
40
50
60
POSITRON ENERGY (Mev.)
180° FOCUS MEASUREMENT
MU-8669

Fig. 2

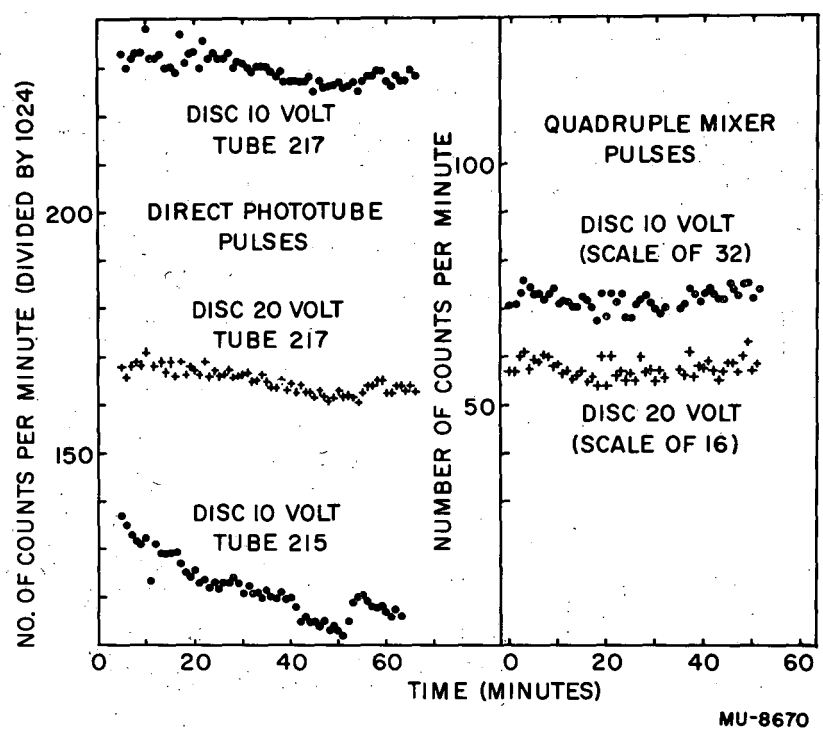


Fig. 3. Examples of Fluctuations Before Adjustments.

to temperature variations; (b) mismatch of the transconductance of the two 6AC7S tubes in the discriminator circuit of a scaler; (c) unregulated 110-volt power supply for the scaler. These conclusions from a test on the fluctuation of scalers are illustrated in Fig. 4. These conclusions likewise apply to slow linear amplifiers.

A temperature test was made on the fluctuation of HP amplifiers by artificially raising and lowering the temperature in the neighborhood of room temperature. No appreciable variation in the counting rate was observed for a $\pm 5^{\circ}C$ variation. A similar temperature test on the fast quad mixer showed large changes in the quadruple-pulse output. A change from $30^{\circ}C$ to $20^{\circ}C$ resulted in decreasing the quad output counting rate from 100% to 64%. This sharp variation is attributed to temperature sensitivity of the germanium diodes. No direct test of the components of the quad mixer was deemed necessary, however. A typical counting rate from the quad mixer, as well as a comparative direct counting rate after the above adjustments were made, is shown in Fig. 5.

Photomeson Production

Preliminary counter measurements have been made on charged-pion production from hydrogen, deuterium, and carbon at 90° to a photon beam having a maximum energy of 300 Mev. For these experiments the 40-inch spiral-orbit spectrometer was used. Pions whose original production energies varied from 14 Mev to 70 Mev were analyzed by the spiral-orbit principle and detected by fast coincidence of pulses from three or four plastic crystals. When the triple-coincidence technique was used, both positive and negative pions were measured at the same time. For these studies a $C\text{-}CH_2$ and a $C\text{-}CD_2$ subtraction technique was used. Because the synchrotron injection system is very sensitive to small changes of magnetic field it is impossible at this time to reverse the magnetic field of the magnet efficiently and in this way check out the difference in efficiency for detecting positive and negative pions with counters. Therefore, for preliminary results, nuclear emulsions are being scanned in order to establish π^+/π^- ratios from carbon in this energy interval. Figure 6 summarizes the scanned data.

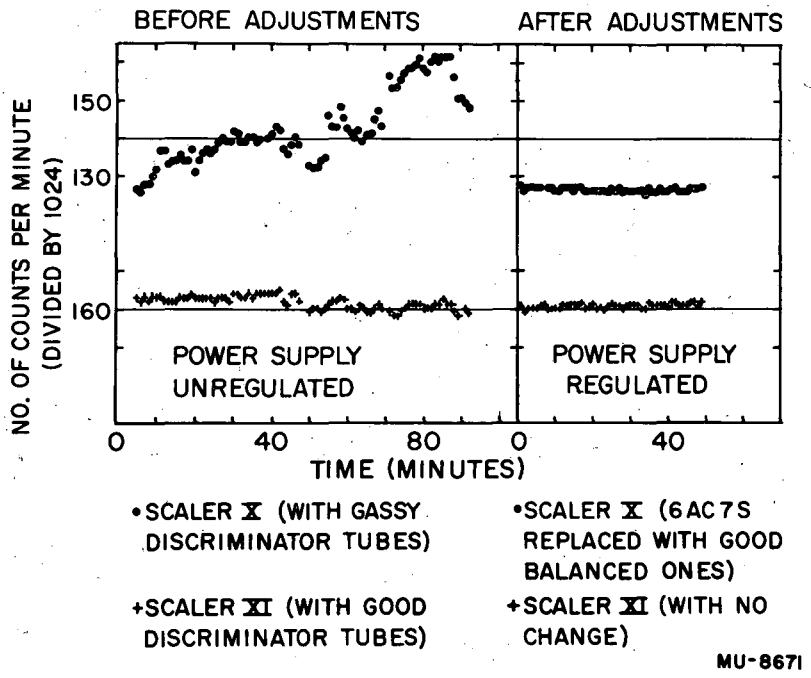


Fig. 4. Improvements Made in Scaler Fluctuations.

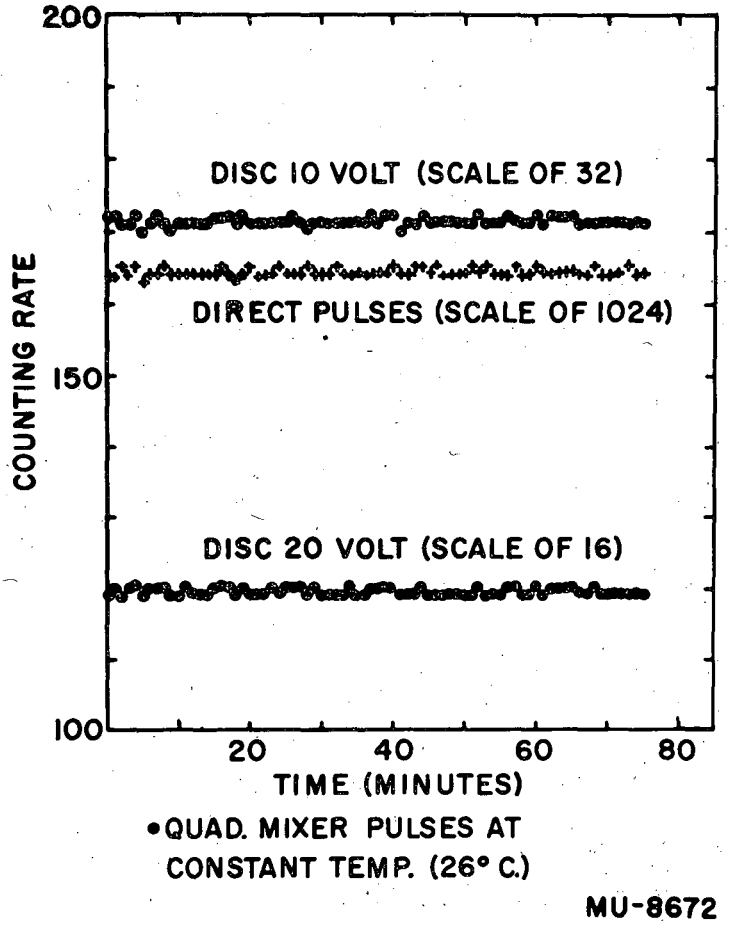


Fig. 5. Final Conditions Reached After Adjustment.

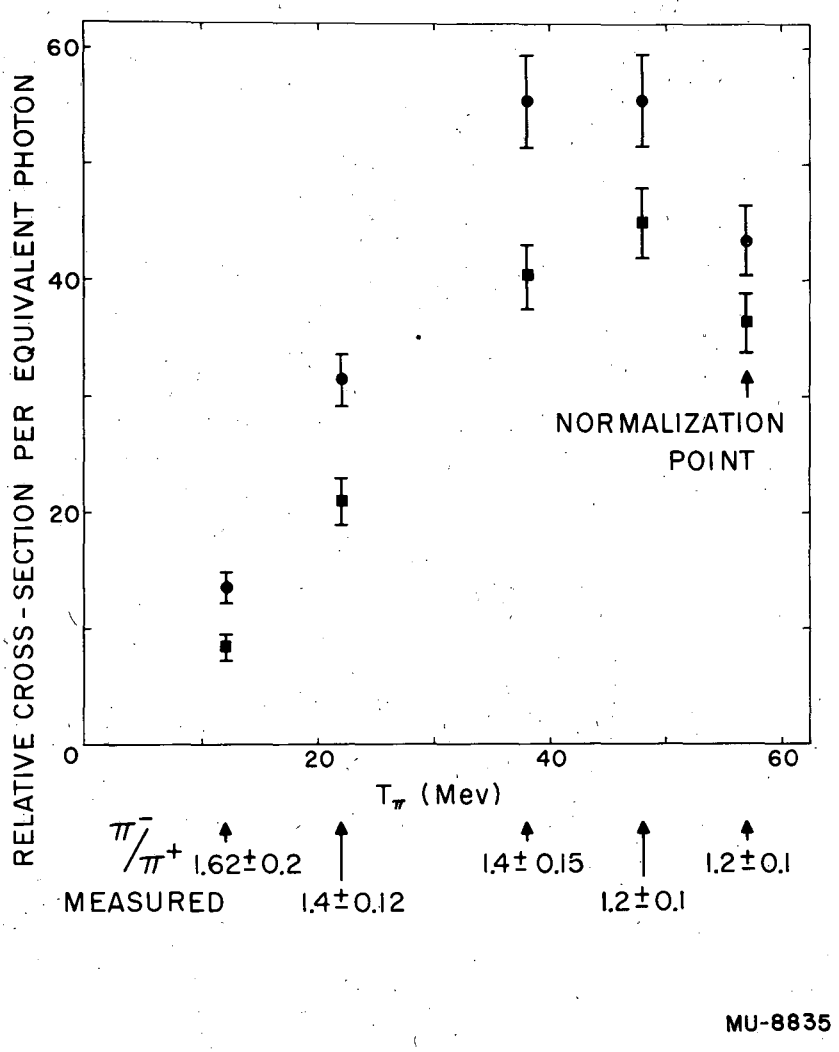


Fig. 6. Energy Spectra of π^+ at 90° to a 300-Mev Photon Beam.

NUCLEAR EMULSION STUDIES: BARKAS GROUP

Research Program

Pair Spectroscopy in Emulsion

Harry Heckman, Peter Giles, and Walter H. Barkas

The energy resolution obtainable from pairs formed in emulsion has been studied using monoenergetic gamma rays of 6, 14, and 17 Mev. The results are being applied to the photons selectively scattered by carbon.

Exposure of Emulsion Stacks to Secondary Particles from Bevatron Target

Harry Heckman

The scanning of a stack exposed 10 inches from the target at 90° to the 4.8-Bev proton beam has yielded 3 k^{+}-mesons, 59 π^{+}-mesons, and 25 π^{-}-mesons to date. The range interval for these events is 1.7 to 5.0 cm. The ratios of $k^{+}/\pi^{\pm}$ and k^{+}/protons are approximately 1/30 and 1/100, respectively. (The density of k^{+}-mesons is approximately 1 per 5.3 mm^{3} of emulsion.) Other work has included the survey of the external pion beams from the bevatron, and orbit studies from various target positions now available in the bevatron. An analysis of the secondary particles from the decay of k^{+}-mesons has been initiated.

Exposure of Emulsion Stacks to Proton Beam of the Bevatron

Sulamith Goldhaber and Frances M. Smith

Stacks of G5 600μ nuclear track emulsion have been exposed in the bevatron proton beam. The different exposures made are described in the following table:

	E (Bev)	Target	Geometry
1	4.8	Ta	90° to direct beam 1 cm from target
2	4.8	C	same as above
3	4.8	Emul	direct proton beam passing through stack
4	5.7	Emul	same as No. 3
5	6.1	Pb	90°, 7 in. from target — exposed in re-entrant wall, west tangent tank
6	6.1	C	same as No. 5

The internal exposures were carried out with the emulsion stack mounted on a plunging probe. Preceding the stack was a 1/4-inch lip target, the purpose of which was to damp radial oscillations and to shift the beam onto the desired target. The targets described above were mounted on the end of the probe. The probe assembly was plunged into the tank at the end of the acceleration cycle of the bevatron. The amount of exposure was determined by the number of secondaries entering a counter telescope that looked at the target from a fixed position. The stacks, which register secondaries from

the Ta and C targets, are being scanned for heavy mesons and hyperons. So far three positive k-mesons have been found in the stack exposed to the Ta target. The following table summarizes the results obtained from measurements of the three k^+-particles and their decay products.

Energy (Mev)	Mass (em)	Secondary*
~ 120	790 ± 190 (MS/R)	steep
~ 120	950 ± 150 (I/R)	steep
~ 120	950 ± 150 (I/R)	flat

*measurements on secondaries not completed

In conjunction with the k-mesons, $45\pi^+$, $55\pi^-$, and 305p endings have been found.

Polarized p-p Scattering at Reduced Energy

Edwin Iloff and Sulamith Goldhaber

A study of the polarization in proton-proton scattering for low-energy protons (10 to 60 Mev) has been made.

The 74-percent-polarized 320-Mev proton beam from the 184-inch cyclotron was slowed down in beryllium absorber to an average energy of 30 Mev. This reduced-energy beam was allowed to enter water-loaded Ilford G.5 emulsions. The emulsions were then scanned for p-p scatterings. From the ranges of the scattered and recoil protons the energy of the incident proton can be determined. Events in the energy range 10 to 60 Mev have been accepted. The elimination of two-prong stars which were not p-p scatters (by coplanarity and range-angle correlation) reduced the number of apparent p-p scatters from 500 events to 200 events. The results to date show no statistically significant deviation from $e \doteq 0$ (e = % left-right asymmetry). If the left- and right-hand scattering are compared from 0° to 90° c.m., the asymmetry appears to be -0.05 ± 0.07 (0.07 is the standard deviation of the statistical error). It might be pertinent to point out that the quantity measured is the product $p_1\, p_2\, \gamma$, where p_1 is the polarization of the incident beam, p_2 is the polarization of the scattering from hydrogen as measured in the H_2O- loaded emulsion, γ is the depolarization factor due to the slowing-down process (γ believed to be 1).

The angular distribution obtained is shown in Fig. 7.

Range Straggling in Emulsion

Walter H. Barkas, Frances M. Smith, and Wallace Birnbaum

The causes of range straggling in emulsion have been investigated as an outgrowth of the meson-mass measurement program. In particular, (a) the effects of emulsion distortion in altering the range and increasing the range straggling have been investigated, and (b) the increase in range variance brought about by the heterogeneity of the emulsion has been evaluated. With particle mass and velocity as variable parameters, a rather complete picture of range straggling in emulsion has been gained, both from the experimental and from the theoretical point of view.

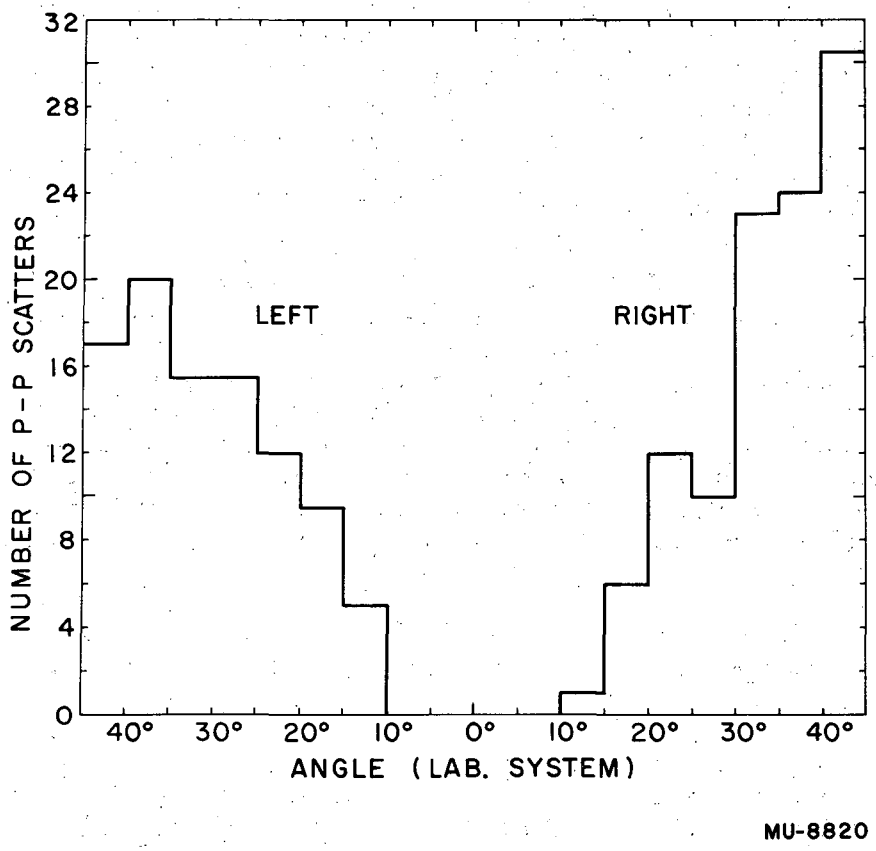


Fig. 7. Angular Distribution of P-P Scatters.

Technical Developments

Hydrogen Blackening of Emulsion

Edward E. Gross

Experiments were conducted on the prevention of hydrogen blackening of plates. It was found that cooling of emulsion and hydrogen down to 0° C was sufficient to retard the blackening for periods of at least one day. It was also found that failure to precool hydrogen before contact with the emulsion causes blackening of the emulsion.

Coordinate Grid System on Emulsion

Harry Heckman

In order to follow tracks from one emulsion layer of the stack into the next, it has been found convenient to contact-print a coordinate grid system directly on the pellicle before processing. A system of grid lines breaking the area up into numbered squares 500 microns on an edge is printed on the emulsion. The error in location is usually not more than 10 microns, and since the original coordinates of each event are printed on the emulsion in the same field of view with it, a substantial saving of time is effected in following tracks from one layer to another.

Processing Equipment

Sulamith Goldhaber, Frances M. Smith, and Roland P. Michaelis

The handling of the large number of emulsions arising from the use of stacks made an improvement in fixing facilities imperative. A large thermostat containing four independent fixing tanks was constructed. Each fixing tank will handle twenty-four 2-by-4-inch emulsions and is fitted with a device that introduces nitrogen bubbles (for stirring) and later admits water for slow dilution of the solution.

Publications

The following abstracts were submitted for the Berkeley meeting of the American Physical Society:

Evan Bailey, "Angle and Energy Distributions of Charged Particles from the Cyclotron Bombardment of Ni and Ag by 200-Mev Protons," University of California Radiation Laboratory Report No. UCRL-2724 (Abstract), Oct. 1954.

F. C. Gilbert, "Analysis of the Disintegration Products from the Reactions of 125-Mev Deuterons with Lithium Nuclei," University of California Radiation Laboratory Report No. UCRL-2725 (Abstract), Oct. 1954.

Dora F. Sherman, "Interactions of 380-Mev Alpha Particles in Ilford G.5 Emulsion," University of California Radiation Laboratory Report No. UCRL-2726 (Abstract), Oct. 1954.

NUCLEAR EMULSION STUDIES: GOLDHABER GROUP

Interaction of 3-Bev Protons in Emulsions

Warren W. Chupp, Gerson Goldhaber, Stephen J. Goldsack, and Joseph Lannutti

Stacks of Ilford G5 nuclear emulsions were exposed in the direct proton beam of the bevatron. The stacks were mounted on a plunging probe with a "lip" target ahead of them. This probe assembly is plunged into the vacuum chamber during the last part of the accelerating cycle in the bevatron. Under the prevailing operating conditions the effect of the lip target was to bring the primary beam over to the emulsion stack, giving the highest flux at the leading edge of the emulsion. The flux then decreased exponentially over the emulsion stack. In the course of area-scanning these emulsions, approximately 2000 proton stars have been examined. Two events of particular interest were observed[1]: (a) the interaction of what is possibly a negative hyperon giving off a 70-Mev proton, (b) the emission and interaction in flight of what is probably a 600- to 700-Mev α-particle. Details of these events will be given later.

A detailed study of the prong distribution of the 3-Bev proton stars has also been made[2]. A summary of the statistics on 118 stars with $N_H \geq 2$ is:

No. of Prongs	2-5	6-10	11-15	16-20	21-25	≥ 25
No. of Stars	45	38	20	8	4	3

Multiple scattering-grain density measurements on a sample of 70 prongs (longer than 3 mm) indicate that the average charged π-meson production is about one meson per interaction.

Study of Secondaries from the Interaction of 4.8-Bev Protons from the Bevatron

Warren W. Chupp, Gerson Goldhaber, Stephen J. Goldsack, and Francis Webb

Stacks of nuclear emulsions have been exposed at 90° to the proton beam of the bevatron (peak energy 4.8 Bev). The stacks were placed in a re-entrant well designed to allow an approach to the plunging target without the necessity of placing the stacks in the vacuum tank[1].

---

1. Gerson Goldhaber, Warren W. Chupp, Stephen J. Goldsack, Joseph Lannutti, and Francis Webb, "Heavy-Meson and Hyperon Production at the Bevatron," Bull. Am. Phys. Soc. for Berkeley Meeting, 1954. (UCRL-2763 Abstract)
2. Joseph Lannutti, Gerson Goldhaber, and Stephen J. Goldsack, "Stars Formed by Protons of 3.2 Bev from the Bevatron," Bull. Am. Phys. Soc. for Berkeley Meeting, 1954. (UCRL-2762 Abstract)

In the exposures here discussed the stacks were at a distance of ten inches from the target with the 0.1-inch aluminum wall of the well as the only intervening material. The stacks were so oriented as to allow the secondaries to travel along the 4-inch direction of the stacks in the plane of the emulsion. (Dimensions of typical stacks used: 4-by-2-inch emulsion, 600μ thick; 24 to 30 emulsions per stack.)

The emulsions are being area-scanned in a region corresponding to a 5-6-cm range of the secondaries in the stack. This will permit accurate mass measurements on the heavy mesons. The alignment was such that a secondary from the target ran its entire length (5 to 6 cm) in only 2 to 5 of the emulsions in the stack. The area-scanning consisted of examining and attempting to identify every particle ending in the field of view. The scanning was carried out by looking at nonoverlapping strips with 1-2 mm separation taken along the 2-inch direction of the emulsions. Tracks that were near the ends of their ranges (as apparent from large multiple scattering) were followed out of the field of view and their endings were examined. The results of the scanning to date are as follows:

Protons*	π^+	π^-**	μ^+***	K-particles	Interactions of charged secondaries	Interactions of neutral secondaries
2580	550	360	13	9	200	240

* Includes D, T, and possible α's from target
** Includes μ^- directly from target
*** Coming directly from target

Because the scanning was done at a fixed range, the above ratios correspond to a comparison of protons of 140 to 160 Mev, K-particles of 110 to 135 Mev, and to mesons of 60 to 80 Mev (including an estimated spread in the target). Until further information on the energy distribution of the different secondaries from the target is available, the ratios obtained from the above table give only very crude estimates of the actual production ratios. Also, for the ratios to be meaningful, the efficiency for K-particle detection must be evaluated. At first sight a K-particle ending looks very similar to a proton ending. Then on further examination, the decay product (usually near minimum ionizing) may be detected. The efficiency for this detection of the decay product may be estimated from the observed number of π-μ-e decays as compared to π-μ decays in which the e was not observable. In this work we found a 90% efficiency for these electrons. A second factor is the relative efficiency for detection of proton endings and π endings. As the π-meson ending is more conspicuous, the observed p/π ratio is probably low, and thus also the K/π ratio.

Measurements on K-particles and their Decay Products

Gerson Goldhaber and Stephen J. Goldsack

The nine K-particles described above form a particularly good set for careful mass measurement, because of their length and good alignment with the plane of the emulsions. In particular, we believe that the separation of masses 950 and 1200 m_e should be possible. So far the preliminary measurements made on five of the nine K's are consistent with the 950 m_e mass value. Good measurements on the decay products are possible only

if the particle comes off at a small angle with the plane of the emulsion or if the particle comes to rest in the emulsion. In four cases out of the nine, good measurements are possible. In the other five cases, the secondaries are too steep for accurate measurement. In three of these cases the preliminary multiple-scattering measurements give $p\beta = 185 \pm 25$, 200 ± 25, 150 ± 40. These and preliminary grain-density measurements are all consistent with a μ-meson of unique energy obtained from the decay of the $K_\mu \rightarrow \mu + \gamma$. The fourth case ($K_8$) gives $p\beta = 60 \pm 12$ Mev/c over the first 4 mm and a continuous decrease in $p\beta$ to $p\beta = 30 \pm 6$ Mev/c after 10 mm. The track is very flat over the first 8 mm and stays in the same plate for 9 mm. It has been followed through the next five emulsions where it travels ~1-2 mm in each plate. Together with the low value and the decrease in $p\beta$ along the track, the grain density remains constant and equal to the plateau value to good accuracy. Preliminary scattering measurements on K_8 give a mass of $980 \pm 260\ m_e$ by the constant-sagitta method (on the last 4 mm) and $1170 \pm 270\ m_e$ by the constant-cell method at a range of 1.5–2.5 cm. This event seems to be a very clear example of the decay of a K-particle by electron emission.

Heavy-meson Production by 5.7-Bev Protons on Nuclear Emulsions

Gerson Goldhaber, Sulamith Goldhaber, and Frances M. Smith

To study particles with very short half lives, exposures were carried out with emulsion stacks in the direct beam at 5.7 Bev. Preliminary scanning of these plates has yielded 2τ-particles and 2 K-particles. One of the τ-particles has been traced back over a range of 8.6 mm to a 13-prong proton star. Further measurements are in progress.

NUCLEAR EMULSION STUDIES: RICHMAN GROUP

Bevatron and Synchrotron

Robert Birge, Roy Haddock, Leroy Kerth, Jack Merritt,
James Peterson, Chaim Richman, Jack Sandweiss,
Donald Stork, Stanley Whetstone,
and Marian Whitehead

At the bevatron, a nuclear emulsion stack exposure has been made at 90° to a target bombarded with 3-Bev protons. The plates were scanned for endings by following dark tracks. Two K-mesons were found, along with 1800 protons and 90 π-mesons.

A second exposure made at 135° to a beam of 4.8-Bev protons revealed, by area-scanning, one K-meson with 2000 protons and 900 π-mesons. The masses of the 3 K^{+}-mesons have been measured, and found, using ionization versus range, to be

(1) $940 \pm 130\ M_e$,

(2) $970 \pm 80\ M_e$,

(3) $820 \pm 160\ M_e$,

and, by multiple scattering versus range, to be

(1) 730 ± 180,

(2) 1360 ± 240,

(3) 830 ± 160.

The secondary particle from one decay has a $p\beta$ of 180 ± 40 Mev/c with approximately minimum ionization.

During this quarter, five emulsion stacks exposed at the synchrotron and at the Stanford electron linear accelerator were processed for Stanley Leonard, who was in the group during the summer, and who is going to measure the trident production for 300-Mev and 450-Mev electrons.

Cyclotron

Donald Stork and Stanley Whetstone

We have exposed a nuclear emulsion stack 6 inches long by 1.5 inches high to positive pions scattered from liquid hydrogen. The 27-Mev pion beam entered the 3.5-inch-long target with an energy dispersion of 1.5 Mev, and traversed the liquid hydrogen parallel to the stack face at an average distance of 1-3/8 inches.

The pion beam was formed by bombarding a thick polyethylene target with the 340-Mev electrostatically deflected proton beam, and magnetically deflecting the pions produced at 0° in the reaction $p + p \rightarrow \pi^{+} + d$. Wedge focusing was used to increase the pion flux in the direction of the liquid-hydrogen target. Six quadrupole focusing magnets were used to concentrate the proton beam at the production target in order to provide a pion source of increased intensity and energy resolution. A background stack and a number of pion-beam-monitoring stacks were also exposed.

The nuclear emulsion stacks are being processed, and scanning of the emulsion for pion tracks will soon be started.

CLOUD CHAMBER STUDIES

Diffusion Chambers

Wilson M. Powell

Two exploratory runs were made with the 4 x 8-foot diffusion cloud chamber at the bevatron in an attempt to determine the paths of the meson beams of various energies. Evidence for the production of a tau meson in the walls of the chamber, decaying halfway across the chamber, was obtained. The great majority of tracks traversing the chamber come from the plunging target.

One run has been made with the 35-atmos. diffusion chamber in a magnetic field of 22,000 gauss. The film has been scanned and two He stars have been observed. The curvature of the paths of some of the mesons has been measured, and preliminary results indicate that the locations of the mesons of various energies agree with their calculated positions.

Negative Pions from Neutron Bombardment of Deuterons

Myron Knapp

In order to obtain information on the neutron-neutron interaction, a cloud chamber filled with deuterium gas was bombarded with the neutron beam of the Berkeley 184-inch synchrocyclotron. The spectrum of the neutron beam, which is produced by 340-Mev protons on a 2.5-inch lithium-deuteride target, is peaked at 300 Mev and extends to 340 Mev. The three reactions $k(n, \pi^- p)d$, $D(n, \pi^- pn)p$, and $d(n, \pi^-)He^3$ were studied. In all, 310 events were examined; the three reactions contributed 208, 80, and 22 events respectively. Laboratory-system angular distributions and energy spectra of the mesons are presented in a UCRL publication now in preparation.*

Disintegration of Oxygen by 300-Mev Neutrons

Melvin O. Fuller

The 300-Mev neutron beam of the Berkeley cyclotron was used to produce disintegrations of oxygen nuclei in an oxygen-filled cloud chamber situated in a 21,700-gauss pulsed magnetic field. Pictures of the "stars" thus formed were reprojected and measured, permitting identification of most of the ejected particles and computation of their energies and momenta. Each star consisted of one or more tracks due to heavy particles of one or two charges, plus the track of the recoil nucleus. The random selection of 602 stars shows approximate percentages according to total prongs as follows: 2-prong, 42%; 3-prong, 29%; 4-prong, 12%; 5-prong, 12%; 6-prong, 4%; 7-prong, 1%; plus one 8-prong star. Energy measurements of the prongs showed 29% having

*Myron W. Knapp, "Negative Pions from Neutron Bombardment of Deuterons" (Thesis), University of California Radiation Laboratory Report No. UCRL-2799, November 1954.

more than 15 Mev, 16% more than 50 Mev, and 8% more than 100 Mev. If 15 Mev was used as a division point between slow and fast particles, the slow particles were 37% alphas, 33% protons, and 22% deuterons, and the fast particles 66% protons, 20% deuterons, and 9% alphas. The energy spectra of the slow particles show maxima at about 2, 3, and 4 Mev for the protons, deuterons, and alphas, respectively, and have the general form characteristic of evaporation spectra. The fast particles, mostly protons, exhibit energy and angular distributions similar to those previously found for heavier elements using nuclear cascade theory. The disintegration is interpreted in terms of fast particles due to the nuclear cascade process in combination with evaporation of slow particles from the excited intermediate nucleus remaining after the cascade process.

GAMMA-RAY PAIR SPECTROMETER

Harlan Shaw, Charles Waddell, Hoyt Bostick, and Selig Kaplan

During August preliminary runs were made at the linac using a NaI (Tl) crystal 3 in. by 3 in. in diameter and a 10-channel pulse-height analyzer for detection of the previously reported γ-ray of 15.2 ± 0.2 Mev produced by proton bombardment of carbon. The purpose of this run was to study the background problems associated with using a NaI (Tl) crystal at the linac for the detection of γ-rays. A preliminary excitation function was also obtained, however, in which the line was produced by an energy of ~17 Mev in the center-of-mass system. This energy is sufficiently low to prove that the energy level in question is not in Be^8, and also that it is not due to a transition from a high-energy excited state (approx. 20 Mev) to the lowest known level (4.43 Mev) in C^{12}.

Analysis of the data for the gamma-energy spectra and the angular distribution from π^0 production by proton bombardment of carbon is nearing completion. When this analysis is completed, the symmetry properties of the total spectrum (i.e., the gamma-energy spectrum integrated over all angles) will provide an indication of the presence or absence of radiative processes other than π^0 decay.

The magnetic group has recently completed a series of measurements of the pair-spectrometer vacuum chamber in a modified steering magnet. A similar set of measurements in the previously used pair magnet will allow the energy calibration made in the old magnet to be used in the new magnet.

PHOTODISINTEGRATION OF THE DEUTERON

Dwight R. Dixon and Kenneth C. Bandtel

Further efforts are being made to obtain differential cross sections at 24°. In an attempt to reduce the background at this angle, several changes in the equipment have been made. A larger liquid deuterium container, 4 in. in diameter, has been constructed. A long vacuum pipe to contain the beam in the vicinity of the target has been provided. A sweeping magnet is available for removing electrons from the incident beam.

Two changes have been made which, it is hoped, will make the identification of protons more positive. Thicker scintillators have been put in the range counters to provide larger signals from the high-energy protons encountered at forward angles. Another scintillation counter has been placed in front of the thick copper absorber which precedes the dE/dx counter. With this arrangement it should be possible to discriminate against electron pairs or small showers that may be produced in the absorber.

A run, incorporating the above features, is soon to begin at the synchrotron.

More data on absorption corrections have been obtained from another cyclotron run.

A STUDY OF THE REACTION $H^1(H^2He^3)\pi^o$ AT 340 Mev PROTON ENERGY

Kenneth C. Bandtel, Wilson J. Frank, Burton J. Moyer, and Larry L. Higgins

If the principle of charge independence is true, the ratio of the reaction $H^1(H^2H^3)\pi^+$ to the above reaction is predicted to be 2:1 at the same angles in the center-of-momentum systems, and hence the total cross sections will be in this ratio. Thus a comparative study of these two reactions will provide a critical test of charge independence.

The reaction $H^1(H^2H^3)\pi^+$ has been studied previously* as a starting point. The angular distribution and yield were obtained. Next, the differential cross sections were compared at a pion center-of-momentum angle of about 45°, where the ratio was found to be 2.3 ± 0.3.**

In order to further test this hypothesis, the cross section for production of He^3 particles has just been measured at three angles. These angles correspond to π^o center-of-momentum angles from about 130° to 160°. Thus a comparison point at the other end of the angular distribution will be obtained. These data have not yet been reduced.

The He^3 particles are correlated with π^o mesons in energy and angle, since this is a two-body reaction with a monoenergetic beam. At any particular angle for the He^3 particles two unique energies are present associated with two unique directions of π^o emission. Elimination of the smaller of these two energies allows a unique He^3 energy to remain which is correlated with a unique direction for π^o emission. Thus a measure of the yield of He^3 particles suffices to determine the characteristics of the reaction without detection of the π^o-meson (which would be difficult in view of the fact that the π^o-decay photons are not uniquely correlated with the π^o-emission direction).

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* Frank, Bandtel, Madey, and Moyer, Phys. Rev. 94, 1716 (1954).

**Frank, Bandtel, Madey, and Moyer, American Physical Society Washington meeting, 1954.

A pulse-height technique was used for detecting the He^3 particles with plastic scintillator material. The pulse heights are photographed from the CRT of a Tektronix 517 scope, on 35 mm Linagraph Pan film. The traces are reprojected and the pulse height read off.

The results are to be presented at the Berkeley meeting of the American Physical Society.

LINEAR ACCELERATOR BETA-RAY SPECTROMETER

Roger W. Wallace

In the last three months a counting array has been constructed for the beta-ray spectrometer, which replaces the Brush recorder formerly used to record the data from the spectrometer. A set of 24 registers is driven in sequence from the output scaler through a stepping relay. The stepping relay is actuated by any submultiple of 60 cycles. A stochastic count was put into these counters, and it was found that the counts were equal in all channels within the statistical uncertainty. The counters were tested on the 24-second $Ag^{110}\beta$ activity, and the measured half life was found to agree with the accepted value.

A fast coincidence circuit with a resolution of 10^{-8} seconds was added to the spectrometer to reduce the random background. A run was attempted using a resolution of 1 percent, which is higher than that used in previous successful runs. The lower counting rate resulting from the thinner target and narrower slits in addition to a lower beam prevented any data from being taken. Another run is planned with the same conditions as the last successful run, but with better statistics made possible by the new counter array.

NEUTRAL-MESON ANGULAR DISTRIBUTION PRODUCED BY 340-Mev PROTONS ON PROTONS

Robert Squire and John Osher

The measurement of the angular distribution of neutral mesons produced in proton-proton collisions at 340 Mev has been investigated. For this purpose a gamma telescope has been developed, consisting of several scintillation counters and a small (10 cm) Cerenkov counter. These have been shown to be efficient for counting (relativistic) cosmic rays. The actual form of the production function of the neutral mesons is deduced from the angular distribution of the decay gammas. The general relationship between these two distributions has been calculated. This calculation can be readily extended to any assumed production function for any particle decaying to two gamma rays, to give the laboratory-system distribution of the gammas.

Several measurements have been made to determine the gamma distribution. Final results have not yet been obtained.

POLARIZATION EXPERIMENTS INVOLVING TRIPLE SCATTERING

Owen Chamberlain, Emilio Segrè, Robert D. Tripp,
Clyde Wiegand, and Thomas J. Ypsilantis

The most recent triple-scattering measurements have been designed to give further information about proton-proton scattering. This means that the middle target (second-scattering target) is of hydrogen, either as polyethylene or as liquid hydrogen. The first scattering is on a one-inch beryllium target, where the scattering angle is 15°. The last scattering is on a 1.5-inch graphite target, with a scattering angle of about 16°.

In broad outline, the beam is polarized in a known way (74%) at the first target, and is analyzed in a known way (about 60%) at the last target. The question under investigation is how the polarization is altered by the hydrogen scattering at the second target.

The triple-scattering experiments should yield experimental values for two new quantities called D and R in the notation of a forthcoming paper by Wolfenstein.* Each of these quantities is a function of scattering angle, and each must be between -1 and +1 at all angles.

At the present time the results of D and R measurements do not check each other as well as we believe they should, so more experimental work is to be done before numerical values can be given.

HIGH-ENERGY PHOTOFISSION OF BISMUTH

John A. Jungerman and Herbert M. Steiner

Several bismuth-loaded D-1 emulsions have been exposed to the bremsstrahlung of the Cal Tech synchrotron in order to check the measurements made earlier with a cancellation type ion chamber. These exposures were made at bremsstrahlung energies of 300, 484, and 500 Mev. These plates are presently being developed. The development seems to be quite critical, and several trial developments have been made. The earlier ion-chamber measurements indicated a rapid increase in the fission cross section of bismuth above the threshold for production of photomesons. The cross section seems to reach a maximum at about 400 Mev, which can be accounted for by postulating a mechanism in which a high-energy photon makes a meson which is subsequently reabsorbed, thereby exciting the nucleus and causing fission. Further experiments are planned using the Cal Tech synchrotron when it is converted to 1000 Mev. This should show whether the cross section decreases above 400 Mev, as can be expected if the mechanism is the one outlined above.

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*Lincoln Wolfenstein, "Possible Triple-Scattering Experiments," Phys. Rev. (to be published).

HIGH-ENERGY PROTON-, DEUTERON-, AND ALPHA-INDUCED FISSION OF SEVERAL HEAVY ELEMENTS

John A. Jungerman and Herbert M. Steiner

A cancellation-type ion chamber has been used to determine the total fission cross sections of U^{235}, U^{238}, Th^{232}, Bi^{209} and Au^{197}. Several runs have been made using the 184-inch synchrocyclotron. The energies of the protons ranged from 100 to 340 Mev, and the deuterons from 60 to 192 Mev, but the α's were investigated only at 395 Mev. The cross sections for the two uranium isotopes and thorium seem to be quite flat in these energy regions for a given type of incident particle. The results are now being analyzed and will be reported shortly.

LIQUID-HYDROGEN GLASER BUBBLE CHAMBER

Luis W. Alvarez, Frank S. Crawford, Jr., H. C. Dittler,
T. F. Gerecke, Douglas Parmentier,
Arnold J. Schwemin, and
M. Lynn Stevenson

A chamber of 4-in. diameter and 2-in. thickness has been constructed and operated successfully. Rates of one expansion every 5 seconds have been sustained over a period of about 3 hours. The liquid-hydrogen consumption rate under these conditions is approximately 2 liters per hour. Twenty liters of liquid hydrogen are required to cool the apparatus prior to steady-state operation.

SCATTERING OF 1.6-Mev GAMMA RAYS

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

Elastic scattering of 1.6-Mev gamma rays from C, Al, Cu, and Pb has been observed for 130° scatters. The presence of electron bremsstrahlung arising from the high-energy Compton recoil electrons has made it difficult to assign reliable cross sections to the elastic scattering at the present time.

Future experiments and calculations are planned that will certainly resolve this difficulty.

DIFFERENTIAL CROSS SECTIONS FOR 30-Mev PROTONS

John Leahy

Time has been spent in improving the resolution of the crystal counter and pulse-height analyzer equipment. Window drifts due to temperature variation have been cut to about 1 percent. This was done in collaboration with Hecht, Silver, and Gantz.

The complete differential cross section for gold has now been measured and that for copper out to 80°. These both show the typical diffraction-type character. Gold has five minima between 10° and 155° spaced very regularly at 25° intervals. Copper shows two minima in the region covered.

ELECTRON-NEUTRINO ANGULAR CORRELATION IN NEON-19

Myron L. Good and Eugene J. Lauer

The differential pumping apparatus was first tried using an electric clearing field to subtract the background due to decays in the drift space. The clearing field produced some extraneous coincidences of an unknown nature and so was replaced by a movable-foil method of subtracting background. Data from a short trial run with the differential-pumping–moving-foil apparatus are being analyzed.

SCATTERING OF 30-Mev PROTONS FROM CARBON

George J. Hecht and Robert Silver

An investigation of scattering of 30-Mev protons from carbon was begun in July and is continuing at the linear accelerator.

Angular distributions of the observed levels of carbon are being taken every 10°, and the elastic proton spectrum as well as the first excited level (4.45 Mev) have been taken at every 5°. Proton groups corresponding to the 7.5-Mev and 9.6-Mev levels have been observed, as well as groups tentatively identified as corresponding to levels at approximately 15 and 20 Mev.

These distributions are measured with a single crystal scintillation counter used with well-defined and accurately reproducible geometry. The angular resolution of the counter is less than 1°. Pulse-height distributions are analyzed with a nine-channel pulse-height analyzer of better than 1 percent resolution. A great deal of effort was expended in stabilizing the pulse-height analyzer to produce good resolution reliably. To optimize pulse-height resolution of the photomultiplier, a pulsed light source producing fast pulses of light (rise time of order 10^{-8} sec) was developed and used to select photomultipliers of better than 2 percent resolution. Such photomultipliers when used in conjunction with plastic scintillators produce an observed resolution (full width at half maximum) of better than 4 percent for 30-Mev protons stopping in the crystal. The difference is ascribed to nonuniform light-conversion efficiency of the scintillator.

The angular distributions of the excited levels of carbon will be compared to those predicted by the Austern, Butler, and McManus theory.

PRESSURE GAUGE FOR LIQUID-HYDROGEN BUBBLE CHAMBERS

William I. Linlor

A pressure gauge is being developed for use in the liquid-hydrogen bubble chamber. Other applications are possible.

The operation of the gauge is based on the change in capacitance of a "parallel-plate" condenser, one plate of which responds to pressure changes.

Because the capacitance change is less than a micromicrofarad, a sensitive detecting instrumentation is needed. The method being investigated consists of building the capacitance into a "termination" for a coaxial transmission line. Variations of the capacitance from a nominal value cause reflections of a pulse. Such an arrangement is independent of the length of the connecting cable.

THEORETICAL GROUP

David L. Judd

An analysis was made of the development of a Taylor instability, beyond the initial stage in which linear approximations are valid, in writing the hydrodynamic equations of motion and the boundary conditions. It was found possible to obtain an exact solution of the nonlinear hydrodynamic equations satisfying the nonlinear boundary conditions at the tip of the Taylor instability. The rates of growth in the initial stage and in the asymptotic region after a long time were obtained, and are in agreement with experiment. (William MacDonald)

An earlier study of the classical radiation from an accelerated charged particle is being continued. (Sidney Bludman)

Some effort is being devoted to studying focusing in magnetic fields from a global point of view, which would not require the exact integration of the orbit equations to obtain the detailed particle trajectory. (Sidney Bludman)

The motion of particles and the transfer of radiation in ionized media are being studied. (Charles Goebel)

Work is continuing on the Tomonaga approximation, and two calculations are in progress. The first is a continuation of Dalitz and Ravenhall's [1] work on iteration of the Tomonaga approximation. (Their first iterated solution showed good agreement with the Tomonaga solution, but there is some question whether the iterations converge rapidly.) The second is a calculation of meson scattering in the charge-symmetric pseudoscalar theory. (Kent K. Curtis)

The approximation scheme for the one-nucleon Green's functions developed previously has been renormalized. The experimental mass and the constants Z_1 and Z_2 were rigorously expressed as free-particle limits of integrals over the kernels appearing in the scheme. The mass and amplitude renormalizations were carried out rigorously; the vertex renormalization was performed by a slight redefinition of the approximation scheme which did not alter the physical assumptions underlying the scheme. General prescriptions for the renormalization were obtained, and a paper embodying these results was submitted to the Physical Review for publication. (Richard L. Arnowitt and Stephen Gasiorowicz)

An invariant characterization of nucleon-nucleon scattering, assuming only the validity of the charge-independence hypothesis, has been developed which permits analysis of any assumed potential without recourse to elaborate phase-shift calculations. Analysis in S-states has shown that static two-parameter potentials of the usual type show little likelihood of representing data successfully, and gives indication that the correct potential possesses a weak energy dependence. Present work centers about the development of rapidly convergent approximation techniques, which in principle are capable of giving both the shape and energy dependence of the two-nucleon potential in each scattering state. (Robert Raphael)

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1. Dalitz and Ravenhall, Phil. Mag. 42, 1378 (1951).

The analysis of the p-p triple scattering and correlation experiments in terms of scattering matrix elements and also the $J \leqslant 3$ phase shifts have been carried out. The problem of extracting the phase shifts from the experimental data has been programmed and coded for the UNIVAC. The experimental data are being reduced to appropriate form, and the UNIVAC will get the problem shortly. A relativistic formulation of the p-p scattering in terms of the scattering matrix has been obtained and used to determine relativistic corrections in the polarization experiments. The relationship between the n-p and p-p scattering matrices under the assumption of charge independence has been investigated. (Henry P. Stapp)

An investigation of the polarization of nucleons elastically scattered by nuclei has been completed and submitted for publication in the Physical Review. (Warren Heckrotte and Joseph V. Lepore)

The consequences of a new principle of gauge invariance for meson-nucleon couplings are being examined. (Joseph V. Lepore and Sidney Bludman)

Work on alpha emission from strongly deformed nuclei continues. The equations for the decay process in the external region of a Bohr-Mottelson nucleus, formerly given only for an even-even nucleus, has been extended to all strongly deformed nuclei. Numerical solutions for the case of Cm^{242} are being calculated for initial conditions corresponding to a "single-particle" alpha model and for alphas emitted uniformly from the nuclear surface. (Benjamin Segall in collaboration with John O. Rasmussen of Chemistry)

The polarization of bremsstrahlung has been studied in collaboration with Robert Karplus, and it has been found that significantly polarized γ-ray beams may be produced with existing electron accelerators. In addition, photonuclear reactions ranging from photodisintegration of light nuclei to photomeson production have been investigated for sensitivity to polarization. Preliminary results appear in a separate report.* (Alfred Reifman)

Calculations were carried out to find the losses in the bevatron due to protons striking the inflector on successive revolutions. Results have been obtained using the assumption of a point source for the protons as they leave the inflector, and work preliminary to computation has been completed, assuming a distributed source. (Ervin Schwarcz)

As a part of the heavy-ion accelerator project, an effort is being made to study in more detail than heretofore the motion of ions in a grid-focused accelerator. The electric fields in gaps closed on one side by a grid structure have been determined by electrolytic tank measurements, and the orbits in the grid section of the heavy-ion accelerator constructed with the aid of the differential analyzer. It appears that the grids in use now are far from perfect, and that most of the losses experienced in grid-focused machines can be ascribed to inefficiency rather than to a physical interception of the beam. It is not clear that the situation can be improved appreciably by grid design, but care in tank flattening and voltage regulation, plus a pre-buncher, might improve the transmitted current considerably. (Lloyd Smith)

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*Robert Karplus and Alfred Reifman, "Polarization of Bremsstrahlung," University of California, Radiation Laboratory Report No. UCRL-2686, September 1954.

Inspired by Brookhaven's success in bringing the accelerated beam out of the cosmotron, work is in progress to develop a similar ejecting system for the bevatron. The differential analyzer is being used to trace orbits around the machine to determine the proper position and size for an ejecting magnet. It has also been successful in predicting the distribution of ions on the last turn following the large energy loss, and is being used to supplement experiments intended to produce a concentrated displaced-ion beam. (Lloyd Smith)

184-INCH CYCLOTRON

Operation

James Vale

Shutdown of the cyclotron for conversion to a higher energy had been scheduled for the first part of October of this year. The shutdown has been postponed until the first part of 1955, owing to the pressure of the medical program.

The lowest winding of the lower coil of the 184-inch magnet has had a low resistance to ground since the fire that occurred in 1946. This resistance has fluctuated somewhat, but had always been in the region of a few thousand ohms. In September this resistance suddenly became only a few ohms, and thus presented a problem. It seemed unsafe to operate the magnet with this shorted point as the ground of the system because of the possibility of a second point's shorting. If this happened, large transient currents would flow, with the possibility of permanent damage to the windings. It was felt that this short could be corrected at the time of the shutdown but that it was essential to operate the cyclotron until that time.

It was extremely fortunate that a winding existed in the lower coil which was not in use. It had been necessary to disconnect this winding originally to get the median plane of the magnetic field in the right place. Even though the number of turns in the winding was less than in the shorted one, the two were exchanged. It was then found that if the current through the magnet was increased and some of the current was shunted through the top coil, operation could be resumed. The increase in power required from the magnet generator under these conditions was negligible and would in itself cause no trouble.

Modification

Richard Burleigh

Magnet

It was originally planned to hard-solder the joints in the conductors between the auxiliary coils and the terminal boxes. In view of the lack of available space, however, this appears to be out of the question. Therefore sample joints have been prepared which are mechanically clamped and soft-soldered. Tests on these joints will be made soon.

About half the parts for the leads for the auxiliary coils have been made, and the drawings for the remainder will be issued shortly.

The auxiliary-coil terminal-box bellows made by Solar to replace the unsatisfactory bellows made on the hill have been received and tested.

A new lifting device for the pole tip has been designed to replace the one that failed.

Radiofrequency System

Further rf tests have been held up pending the installation of the operating blades.

All blades are now finished. The power required to drive the blades, however, is higher than expected. It is believed that the additional power is being absorbed in friction between the butt of the blade and the mounting, and with this in view various changes have been made to the mounting and clamp bars--without, however, any positive results to date.

Past experience with test blades indicated damage to the copper plating on both the blade butt and the mounting at the area of contact. The copper plating is being removed in this area and a separate means for carrying the rf current over the joint is being provided.

Design work is largely completed on the device for measuring the gap between the blade and the stator.

The capacitor vacuum tank was originally vacuum copper coated and, while this was at first thought to be satisfactory for carrying leakage rf current, it has now been determined that the coating was of insufficient thickness; therefore the tank is now being lined with sheet copper.

Insulators have been ordered for insertion between the flexible copper hinges on the movable panels and the capacitor vacuum-tank liner, as the preliminary rf tests indicated sparking between these members.

Miscellaneous

The trouble previously experienced with the booster pumps for the 20-inch diffusion pumps has been remedied by the addition of extra heaters.

The trimming coils are complete except for measures to cure a short in one coil.

The design work on the ion source and on the movable scatterer in the dee is almost complete.

Work has started on the steel boxes for the meson cave shielding, and the concrete blocks are out for bid.

Design work on the enlarged deuteron cave and new medical cave is almost complete.

It has been decided to move the control room to Building 80 and to move mechanical vacuum pumps outside the building.

The shutdown is set for January 6, 1955, with the possibility of a further postponement due to an extension of the current cancer-research program.

60-INCH CYCLOTRON

REPORT ON CONVERSION

G. Bernard Rossi

Introduction

The 60-inch Cyclotron, at Crocker Laboratory, was made operative in April 1939 under the direction of Dr. E. O. Lawrence. Since that time it has been in continuous productive operation, except for three major overhaul periods. The first such overhaul occured in 1945, and achieved the following:

(a) Rewinding of magnet coils, increasing the ampere turns.
(b) Installation of Backus-type continuously pumped oscillator tube, replacing the Salisbury circuit.
(c) Complete rewiring of all electric circuits, including replacement of all underground wiring.
(d) Erection of structural steel for radiation-protection water tanks.
(e) Installation of new dees.
(f) Installation of ion-source vacuum lock for removal of source without "letting down to air".

This shutdown was directed by Dr. Joseph G. Hamilton and Dr. Thomas M. Putnam, with the mechanical engineering under the supervision of Malcom Webb; the Radiation Laboratory Engineering staff, directed by Dr. Miller and supervised by John McCharles, provided for the electrical changes.

The result of the alteration was an increased over-all efficiency of operation, which permitted energy increases from 14-Mev to 18-Mev deuterons. Attempts at magnet shimming via external Rose shims proved nonproductive; central shimming (pyramidal) resulted in increased output for all particles. The removable ion source and holder permitted ion-source experiments, increasing the alpha beam from 1 μa external to peaks of 25 μa at 36 Mev.

The second overhaul resulted from a badly burned dee-stem rf conductor, and led to a complete overhaul of the internal rf current-carrying system. The ensuing repairs lasted from April 1949 through November 1949, and had the following main objectives:

(a) Replacement of tapered pole faces with 72-inch cylindrical sections and reduction of the magnetic air gap by 0.5 inch.
(b) Rebuilding of water-cooling systems to provide increased cooling for the rf system.
(c) Installation of new dees, tank liners, spiders, and dee stem liners, fabricated of 1/8-inch copper.
(d) Installation of rf deflector system.
(e) Reworking of electric circuits to provide standardized interconnections.
(f) Reworking of the mechanical pumping system to decrease roughing time and increase tank-pumping speeds.
(g) Relocation and rewiring of the control desk.

Five years of uninterrupted operation followed the 1949 overhaul. Alpha beams of 50 to 75 μa at 40 Mev were attained; heavy-ion beams of C^{+6}, N^{+7}, and Ne^{+10} were developed with sufficient intensity for use in biology, physics, and chemistry research. Record amounts of productive bombardments were made with an over-all innage time approaching 85 percent for the five-year period.

In November 1953 the future demands upon this machine were reviewed by members of the 60-inch staff and representatives of Dr. Seaborg's and Dr. Thornton's groups. Plans were aimed at developing an accelerator flexible enough to run with heavy or light ions at adequate intensities and energies for research demands. Ensuing conferences with the above groups, augmented by Harry Keller of the Magnet Measurement Group, led to the following conclusions:

(a) Operation of the oscillator at two frequencies would permit acceleration of heavy ions in a magnet field better shaped for their acceleration.
(b) Rose shims, internal to the vacuum system, would permit extraction at 26-inch radius instead of the former 24.5 inches, thus providing increased $\beta\rho$.
(c) Time and dollar expenditures in converting the 60-inch machine would be much less than for other available accelerators.
(d) Higher energies of lighter ions could be expected without loss of beam intensity.

A shutdown was planned for April 19, 1954 to accomplish the changes outlined above. The 60-inch staff functioned in this planning in the following capacities:

B. Jones: theoretical evaluation of extraction radius changes and deflector requirements,
C. Corum: engineering of mechanical changes,
K. Jenkins: electronics engineering.

The University of California Radiation Laboratory, with permission of the Atomic Energy Commission, made its shops available for fabrication of most of the new parts; offered the services of Harry Keller and the Magnet Testing Group for model and full-scale measurements; and provided engineering assistance through consultation with Marvin Martin, William Carpender, and Jack Riedel.

Objectives

The planning for the shutdown period was directed toward increasing the usefulness of the cyclotron to all research groups. For this purpose, parameters of field shape, oscillator frequency, and extraction radius were chosen to permit easy changes from light particles (d_2, H, He) to heavy particles (C^{+6}, N^{+6}, Ne^{+9}, O^{+6}, etc.) without loss in beam intensity. To accomplish this, it was decided to provide for two fixed frequencies of oscillator operation, chosen to permit light-ion acceleration at the higher and heavier-ion acceleration at the lower frequency. Settings for these frequencies were chosen to permit heavy-ion operation within the range of magnetic flux available and as close to the specific light-ion shimmed field as possible. To accomplish this, a magnetic field of 16,000 gauss (central) was selected, with a slope of 0.06 gauss per inch between 4 inches and 20 inches. The fall-off at 26 inches was

designed to be 2%. This field choice set an operating frequency of 12.3 megacycles for the light ions (high frequency); 11 megacycles was chosen for the lower frequency to preserve an energy of about 10 Mev per nucleon.

Physical Changes

The major physical changes made during the conversion period were grouped as follows:

Magnet

(a) Replacement of the 75-kw generator with one of 250-kw output.
(b) Rewiring magnet hookup from full series to series-parallel.
(c) Removal of tank-lid filler plates and installation of internal shims to produce the desired field.

Internal rf system

(a) Extension of dee-stem tank 15 inches to provide wider frequency range.
(b) Replacement of dee-stem liners.
(c) Installation of adjustable high-frequency grounding spider.
(d) Slotting of dee-stem steel support tubes for installation of frequency-shifting mechanism
(e) Installation of new dees with replaceable exit walls.
(f) Installation of new tank liners shaped to accommodate internal Rose shims.

Heat-Exchange System

(a) Replumbing of magnet-oil supply system to provide 100 gpm flow to each tank from a paralleled system.
(b) Installation of auxiliary water-pumping system to provide 150 gpm to the oil heat exchanger.
(c) Installation of Grisholm-Russell shell and tube oil heat exchanger.
(d) Removal of old heat exchanger from the cooling tower.
(e) Removal of rust and scale from cooling tower and painting tower with three protective coats.

Miscellaneous

(a) Running series of field plots on full-scale model, including magnetization curve, radial curves at five field settings, and an azimuthal series.
(b) Construction of an annex to Crocker Laboratory to house both the 250-kw and 75-kw generators and the oil heat exchanger with its associated pumping equipment.
(c) Rearrangement of the target area to provide more working space.
(d) Completion of all necessary electric control changes to accomodate new equipment control.
(e) Replacement of main supports for vacuum chamber with new ones designed for greater ion-source motion.

Results

The Magnet Measurement Group completed the field plots on June 16, 1954, making the final assembly of all other components possible. Baking of the tank and oscillator system started July 6, 1954. The work of tuning the oscillator for both low and high frequencies continued until July 12, 1954,

when the first beam was sighted at the higher frequency. C_{12}^{+6} ions were accelerated first, so that direct observation into the accelerating chamber could be made without radiation danger. Internal He^{+2} beams of 120 μa were recorded by July 15, 1954, which permitted a study of beam shape, fall-off with radius, and increases of intensity with dee voltage.

These studies indicated that the beam envelope was well within the dee height over the radial distance examined (15 in. to 25 in.). The beam was not reaching extraction radius (25.5 in.) owing to low dee voltage. Efforts made toward external extraction of the beam were rewarded on July 26, 1954 with 10 μa of alpha-particles at 50 Mev. This external beam was increased to 30 μa by July 29, 1954, when the first productive use of the beam was made by research groups.

Some salient beam characteristics are illustrated in Figs. 8 and 9. Both represent the envelope of the beam as it crosses the axis between the dees. A 0.001-inch stainless steel foil was placed in this area and, under resonant conditions for external particles, the beam was allowed to burn the foil. The horizontal marking to the right of the photo indicates the position and shape of the beam after deflection. The midpoint of this beam marking occurred at 29.75 inches from the pole-face center; the left-hand outline (internal beam) covers the radii from 15 inches to 25.5 inches. The midpoint of the bulbous end of the internal beam occurs at 24.25 inches and closely duplicates the calculated value for $n = \frac{dH}{H}\frac{R}{dR} = 0.2$. At this critical value of n a coupling of radial and vertical beam oscillations occurs, adding in the vertical direction. It is apparent that the coupling is not serious here and that magnetic focusing again is effective between 24.25 inches and 25.5 inches. Figure 8 was made with 50-Mev alpha particles with dee voltage in excess of external beam threshold.

At a later date the oscillator frequency was changed to 12.5 megacycles, which was equivalent to 52 Mev. Efforts to extract the beam were unrewarding. Figure 9 is indicative of the reason for this failure. It can be noted that the beam terminates shortly after traversing the n - 0.2 point, at r = 25 inches. This was verified by direct beam measurement as a function of radius for various dee-voltage levels. The conclusion drawn from these data was that sufficient dee voltage was not available, under these conditions, to accelerate more than a small portion of the internal beam to extraction radius.

A return to the 50-Mev conditions provided the data for Fig. 10-- a plot of beam intensity as a function of total dee voltage. The dee voltage values shown are not absolute, but are relative values. Under the conditions existing when these data were taken the upper value of dee voltage was 240 kv, indicating that the external beam threshold was exceeded by only 20 kv. Figure 11 indicates the internal beam intensity versus radius at 235 kv. The sharp fall-off of beam from 24.75 inches to 25.5 inches is again indicative of the threshold dee-voltage conditions for extraction. Under these circumstances, extraction efficiencies as high as 90 percent of the internal beam were realized.

Fig. 8. Beam Envelope of 50 Mev α Particles.

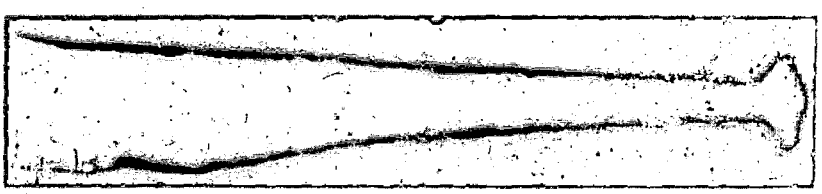

Fig. 9. Beam Envelope of 52 Mev α Particles.

ZN-1076

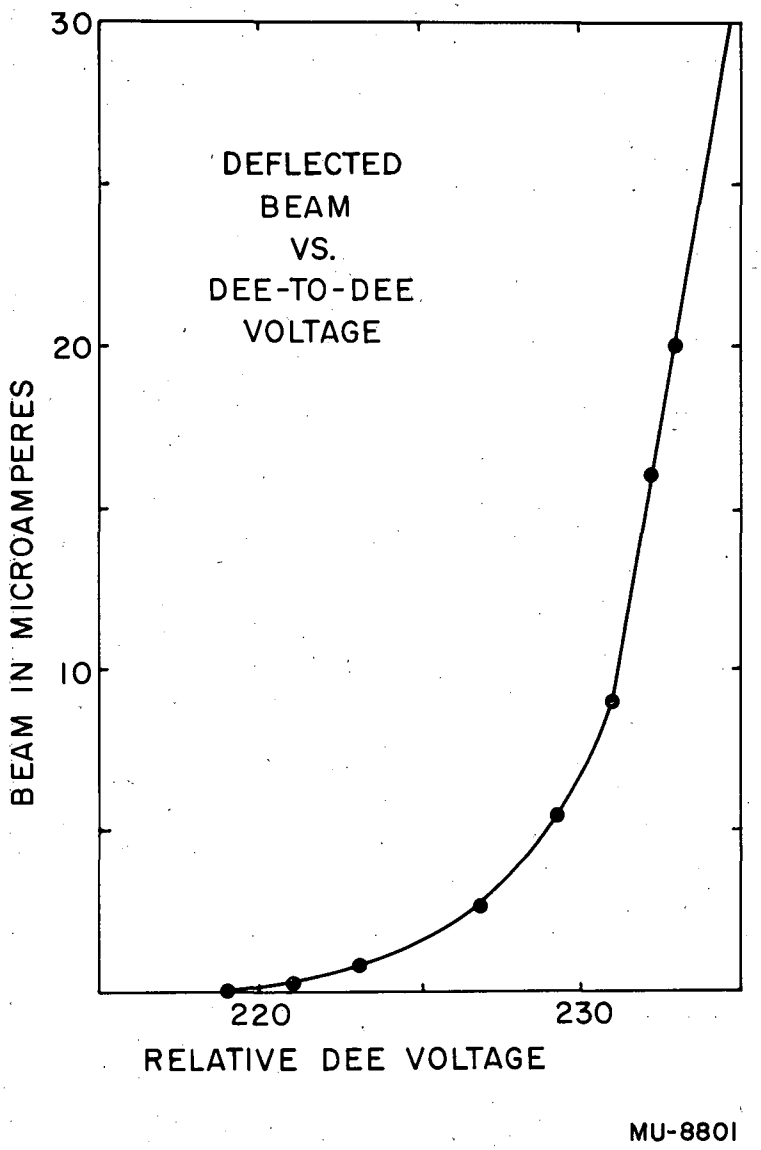
DEFLECTED
BEAM
VS.
DEE-TO-DEE
VOLTAGE
30
20
10
BEAM IN MICROAMPERES
220
230
RELATIVE DEE VOLTAGE
MU-8801

Fig. 10

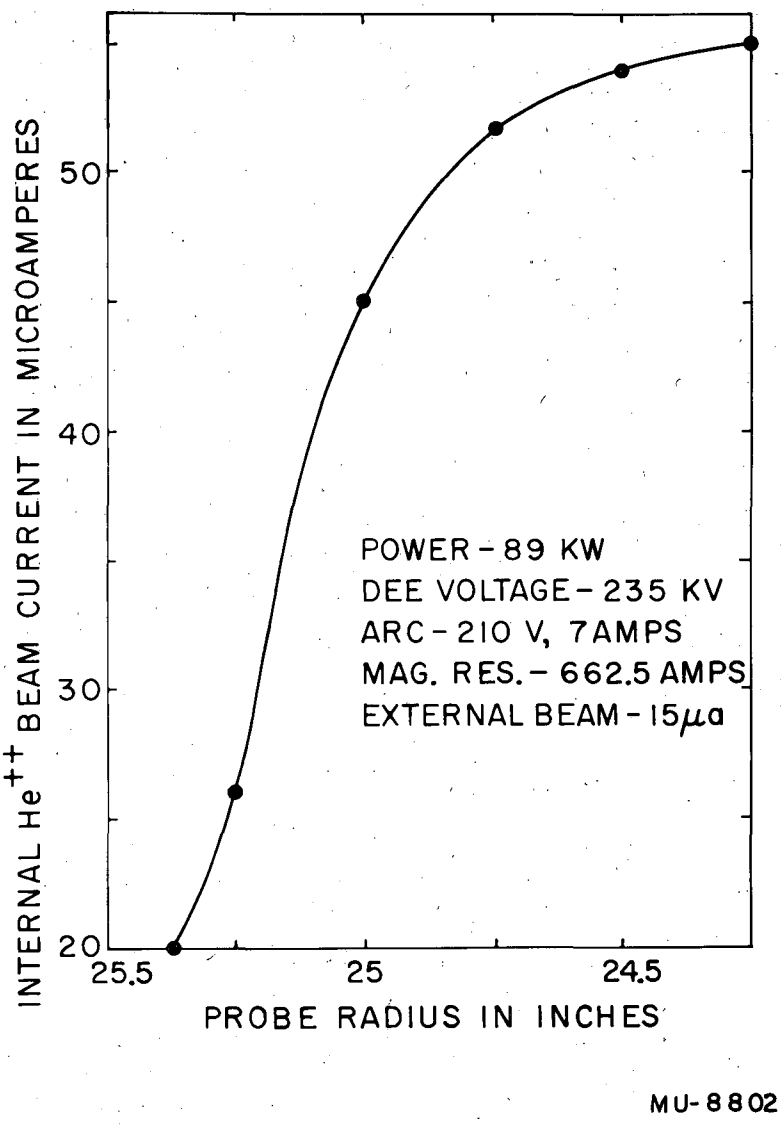

Fig. 11. Internal Beam Versus Radius.

SYNCHROTRON

Research

A. Carl Helmholz

During the period August, September, October, the operation of the synchrotron was, in general, disappointing. A great deal of time was spent fruitlessly in trying to improve the beam, which was far from good. The net result was that the experimental program did not proceed so rapidly as it should have. It is probable that the machine will have to be shut down in the next few months for an overhaul, and at that time, a doughnut section for linear-accelerator injection should be installed.

J. Anderson, Robert Kenney, and C. McDonald have made measurements of the angular distribution of quanta from 335-Mev electrons on the 0.020-inch Pt target, using the pair spectrometer as the measuring instrument. A large hole in the Pb shielding where the primary collimation is usually done allowed a wide range of angles to pass through. A 1/8-inch collimator, which could be moved to different angles from the target, was followed by a sweeping magnet and the pair spectrometer. The angular distribution followed an $e^{-c|\theta|}$ rather than an $e^{-c\theta^2}$ law. The half angles were 8.879 ± 0.048 milliradians for 200-Mev quanta, 8.592 ± 0.056 for 250 Mev, and 7.679 ± 0.096 for 300 Mev. The errors are purely counting errors. Further experiments with a thicker target are planned.

Gordon Repp and R. S. White have made measurements on the π^+ yield at large angles (including 180°) to the beam with H and D as targets. The data are being worked up at the present time and will be written up as a report.

H. Easterday, W. Imhoff, and Victor Perez-Mendez have used their π-μ gear, which is now working satisfactorily, to look at the π^+ yield from a number of light elements. They were unable to get enough statistics in the first run, but plan to measure Be^9, B^{10}, B^{11}, and C^{12} to see any isotopic or binding-energy effects.

Several short runs for members of the film group and a short run on nitrogen for Professor Libby were made during the period.

Ryokichi Sagane and Walter Dudziak used a considerable amount of the running period for their work on π^+ and π^- yields at low energy. These results are reported elsewhere.

Operation

George McFarland

During this report period the synchrotron was used continuously for physics research. The beam intensity that could be obtained from the machine varied from time to time, and every effort was made to keep the beam intensity at its highest level. There is still considerable voltage shifting of the magnet-

energizing supply. The glass shop at ORL has been making glass doughnut sections for use in the synchrotron in conjunction with the proposed electron-accelerator injector. It is hoped that these sections can be installed early next year.

BEVATRON

Edward Lofgren

Recent work at the bevatron is being included in a comprehensive report that will be issued as a separate paper, UCRL-2822.

Information Division
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