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PHYSICS DIVISION QUARTERLY REPORT

February, March, April 1954

June 21, 1954

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Berkeley, California

PHYSICS DIVISION QUARTERLY REPORT

February, March, April 1954

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PHYSICS DIVISION QUARTERLY REPORT
February, March, April, 1954

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

GENERAL PHYSICS RESEARCH

POLARIZATION STUDIES

Owen Chamberlain, Emilio Segrè, Robert Tripp, Clyde Wiegand,
and Tom Ypsilantis

Mechanism of Polarization by Nuclei

Following the results given in our last quarterly report (also Phys. Rev. 93, 1430 (1954)) an interesting mechanism by which one can explain the polarization was independently proposed by several authors (Fermi; Malenka; Lepore, Heckrotte; Snow, Sternheimer, and Yang). In brief it is that in elastic scattering at high energy the polarization is produced by the same (L·S) interaction that is responsible for the shell effects in the low-energy states of nuclei.

Patterns of diffraction scattering that take this effect into account have been calculated with several types of nuclear potential by the authors mentioned above, and we have undertaken an experimental study of the same.

The chief difficulties are the high geometrical precision required and the importance of choosing the proper energy of the scattered beam. Ideally we would like to count only elastically scattered particles, but this, starting with 340 Mev, has proved unfeasible and we have limited ourselves to accepting only scattered protons that had lost less than about 5 Mev in the scattering.

We have studied C, Al, Ca, Fe. For heavier elements the geometrical difficulties due to the narrower diffraction pattern increase substantially.

The cross sections for left and right scattering for Al are shown in Fig. 1, and the corresponding values of $e = \frac{I_l - I_r}{I_l + I_r}$ can be seen in Fig. 2.

It is apparent that the left and right diffraction patterns are different and that some of the qualitative features predicted by the model based on L·S coupling are present, but they are washed out--mainly, we think, because it is not possible to observe only the truly elastic scattering.

If we do not restrict the energy as indicated above, we obtain patterns with less pronounced fluctuation of e.

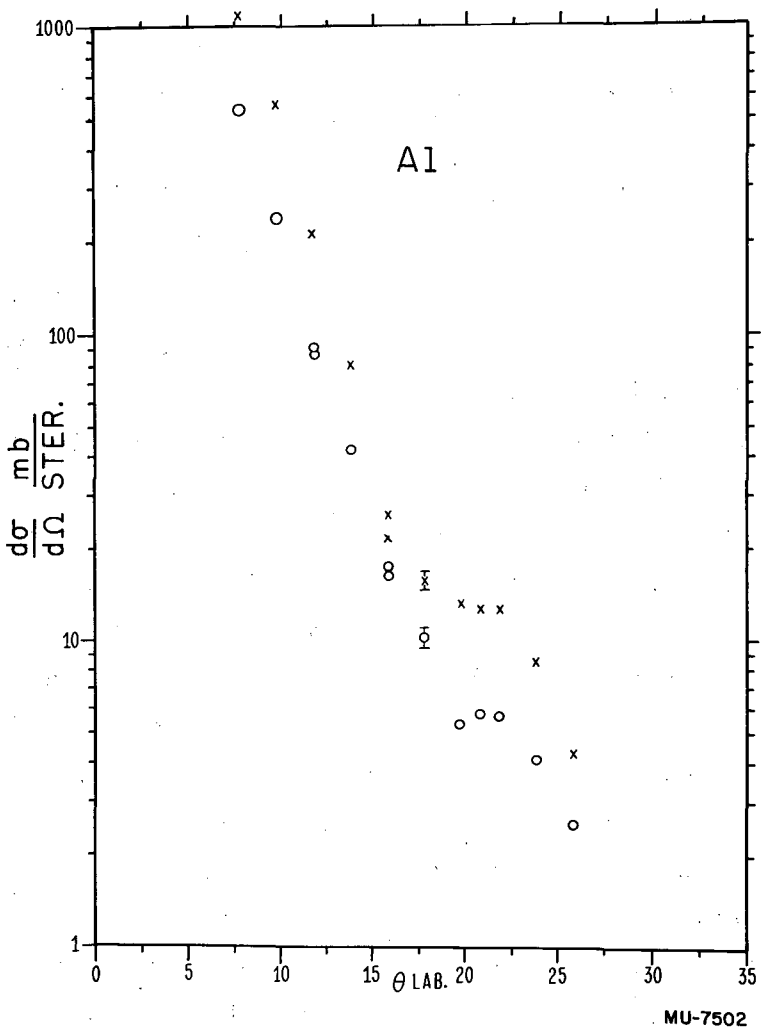


Fig. 1

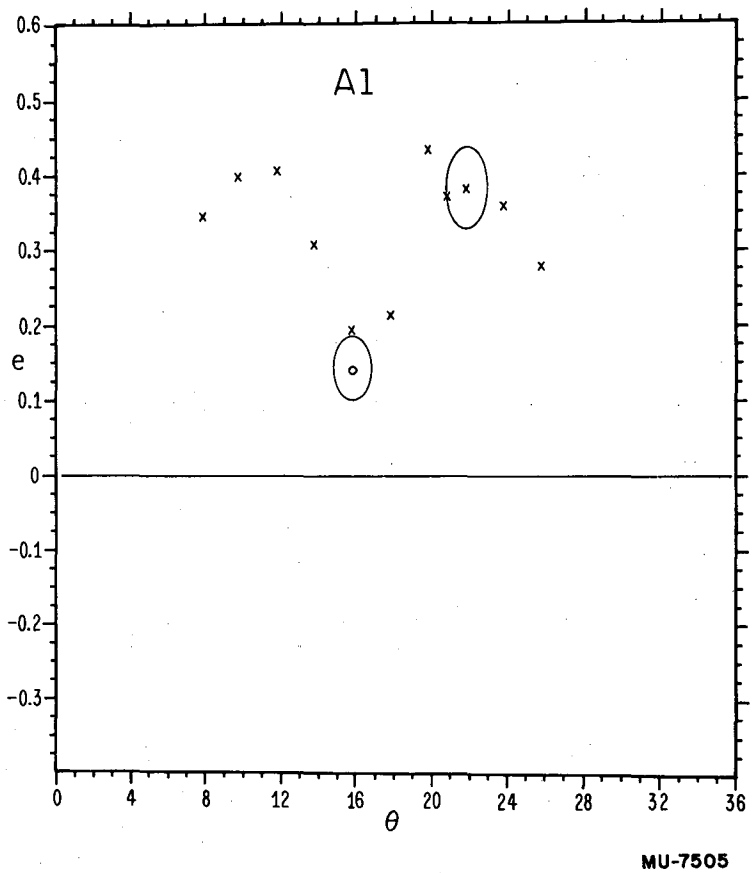


Fig. 2

The polarization persists--although somewhat diminished--even when the scattering is inelastic, e.g., when the energy is degraded by an amount corresponding to nucleon-nucleon scattering. Figure 3 shows the e obtained by scattering at $\theta = 15^{\circ}$ from C as a function of the energy of the scattered proton.

p-n Collision Polarization

We have performed an exploratory experiment bombarding C with polarized protons (320 Mev) and detecting the neutrons emitted at $\theta = 16^{\circ}, 20^{\circ}$. The left-right asymmetry e is 0.23 ± 0.15 and 0.15 ± 0.07, respectively.

We plan to repeat this experiment, using D instead of C in order to have a collision with a nearly free neutron.

Polarization of Deuteron Beam

The 190-Mev deuteron beam can be polarized by scattering in a manner similar to that of the proton beam giving a polarized beam of 170 Mev energy. A second scattering must produce a beam of an intensity

$$I(\phi, \theta) = A(\theta) + B(\theta)\cos\phi + C(\theta)\cos^2\phi$$

where A, B, and C depend on the special scattering process.

For carbon limiting the energy to >160 we have obtained at $\theta = 19.8$ a pattern as in Fig. 4. This shows that C is very small.

It has been pointed out by Ruderman that if the mechanism of polarization is the L·S interaction the smallness of C is consistent with the smallness of this interaction compared to the main nuclear potential.

SMALL-ANGLE NEUTRON-PROTON SCATTERING AT 270 MEV

J. W. Easley and O. Chamberlain

A measurement of the relative neutron-proton scattering cross section for 270-Mev neutrons has been made at the center-of-mass angles of 37.7°, 21.4° and 10.7°. Preliminary figures for the ratio of the center-of-mass cross sections to that at 37.7° are 1.11 ± 0.07 at 21.4°, and 1.47 ± 0.09 at 10.7°. Comparison with prior work[1] leads to a ratio of the cross section at 10° to that at 170° of 0.68 ± 0.16. A complete analysis of the data is in progress at the present time, and corrections to these preliminary results are not expected to exceed 5%.

---

[1] Kelly et al., Phys. Rev. 79, 96 (1950).

This result is in disagreement with the work of De Pangher[2], which indicates a constant cross section from approximately 45° to 15°.

The method of measurement was the same as that employed for the similar experiment at 90 Mev[3]. The thickness of the converter and crystals Nos. 1 and 3 was approximately doubled, and the thickness and shape of the absorbers were modified for the higher particle energy involved. The greater portion of the data was obtained with a low-energy cutoff of 200 Mev.

---

[2] John De Pangher, A High-Pressure Cloud-Chamber Investigation of Protons Scattered by 300-Mev Neutrons (thesis), University of California Radiation Laboratory Report No. UCRL-2153, March 1953.

[3] O. Chamberlain and J. W. Easley, Phys. Rev. 94, 208 (1954).

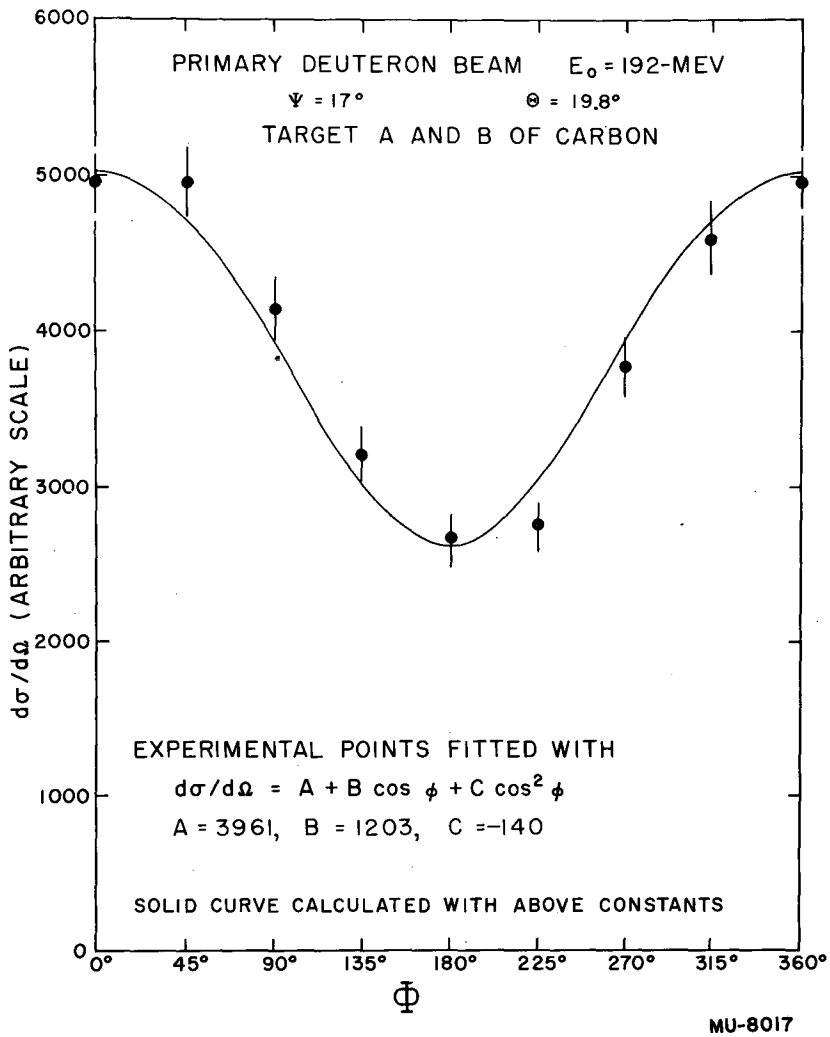

PRIMARY DEUTERON BEAM E_0 = 192-MEV
Ψ = 17°
Θ = 19.8°
TARGET A AND B OF CARBON
EXPERIMENTAL POINTS FITTED WITH
$d\sigma/d\Omega = A + B \cos\phi + C \cos^2\phi$
A = 3961, B = 1203, C = −140
SOLID CURVE CALCULATED WITH ABOVE CONSTANTS
$d\sigma/d\Omega$ (ARBITRARY SCALE)
6000
5000
4000
3000
2000
1000
0
0°
45°
90°
135°
180°
225°
270°
315°
360°
Φ
MU-8017

Fig. 3

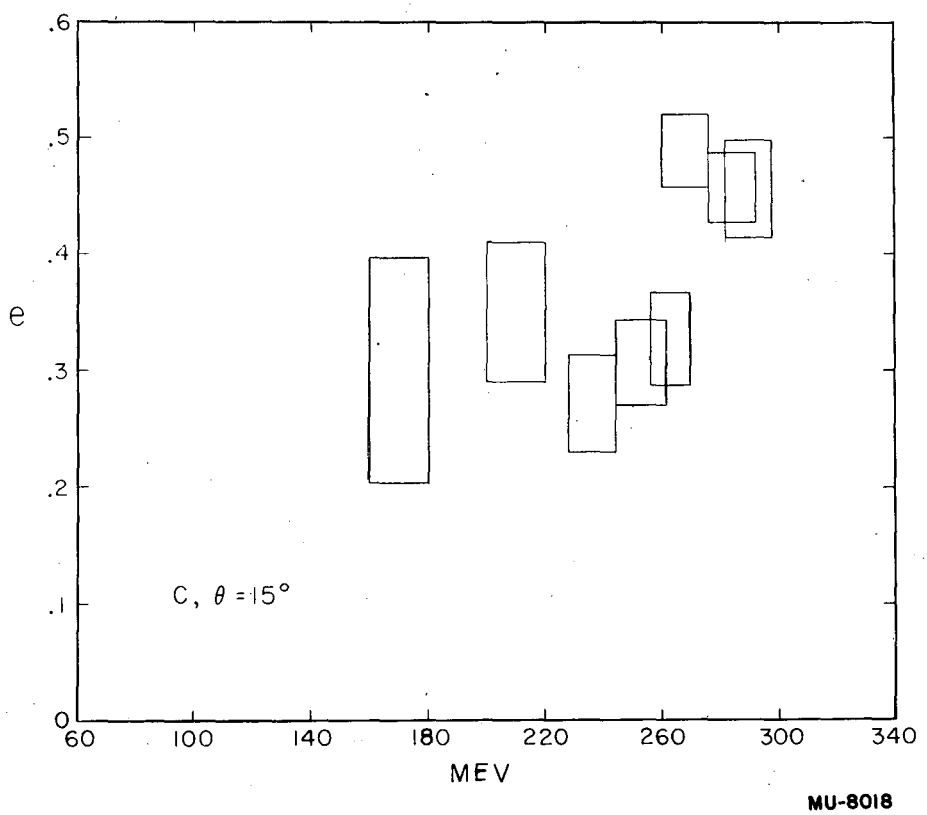


Fig. 4

MESON RESEARCH WITH THE SPIRAL-ORBIT SPECTROMETER

Ryokichi Sagane and Walter F. Dudziak

The studies that were undertaken and accomplished during this period with the spiral-orbit spectrometers are briefly summarized. Furthermore a summary is given of the modifications that were necessary.

Research with the 22-inch Spiral-Orbit Spectrometer: Photomesons

As pointed out in the previous report, a study was undertaken of the low-energy photomeson production from hydrogen, deuterium, and carbon by means of nuclear emulsions, using a subtraction technique. The relative yields of π^+-mesons from hydrogen and carbon appear in the earlier report. Because one of the magnet coils shorted out, this study was temporarily discontinued. However, the following preliminary ratios for a pion energy $T_\pi = 11$ Mev were obtained:

$$\left(\frac{\pi^-}{\pi^+}\right)_{carbon} = 1.86 \qquad \left(\frac{\pi^-}{\pi^+}\right)_{deuterium} = 1.1 \qquad \left(\frac{\pi^+_{hydrogen}}{\pi^+_{deuterium}}\right) = 1.2$$

Both coils of the 22-inch magnet were taken apart. On inspection, certain modifications of the indirectly water-cooled coil were found necessary to correct causes of failure appearing after one year of performance. These modifications are not indicated in the original drawings, and therefore are described briefly here. Figure 5 shows how the cooling fins and coil "pancakes" were assembled in five-parted sandwiches. The copper fin, A, was in the middle, flanked on each side by two slightly smaller sheets of 12-mil insulator made of glass silicone fiber, B. On either side of this was the pancake of coil, consisting of 42 turns of solid copper conductor, 1/8 by 1 inch, with each turn insulated from the next by a 7-mil glass-silicone tape. The whole assembly was originally too closely fitted around the insulating layer E surrounding the cylindrical 22-inch magnet pole. The motion of the fins during contraction and expansion bruised the insulators E and B, resulting eventually in short circuits.

In the modification, the original glass-silicone varnish on A was sandblasted off and the inner diameter of the fin was increased by 1/2 inch. B was replaced by a 1/32-inch hardened glass-silicone insulator. The coil spacer D was originally of brass covered with silicone-glass and dipped in silicone varnish; this was replaced by a spacer made of mycalex insulator. The two layers of 12-mil glass-silicone fiber at E, covering the cylindrical surface of the 22-inch-diameter pole, were replaced with a 1/32-inch hardened glass-silicone insulator.

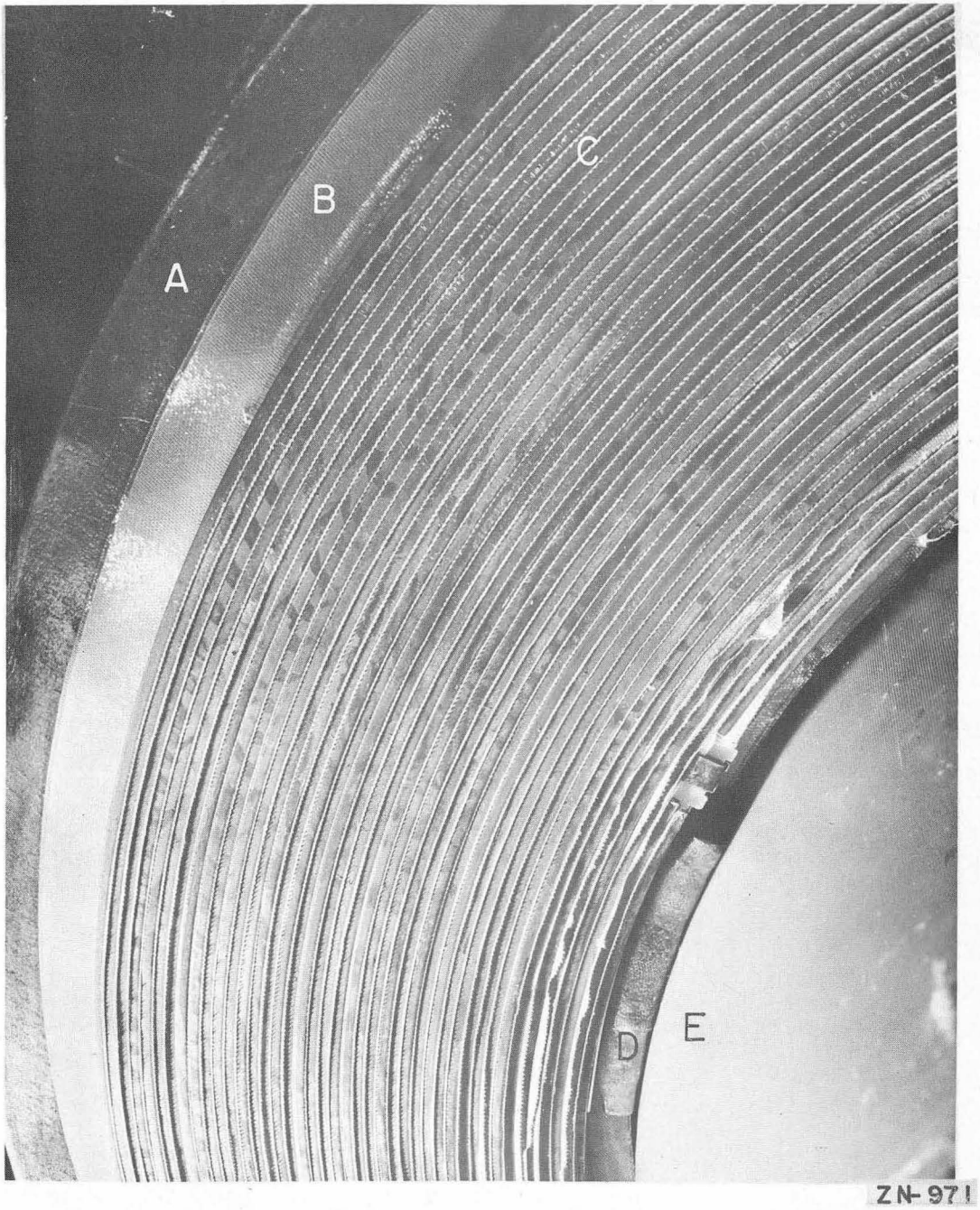


Fig. 5

Figure 6 illustrates the other changes that have been made, as follows:

(a) Originally the electrical terminals were 7/8-inch threaded copper screws. These caused the brass nuts that secure the power cables to the magnet to bind. To remove this difficulty the terminals were replaced by solid copper bars containing the necessary bolt holes for securing the power cables.

(b) The position of the water inlet and outlet to each coil was changed so that in the modified condition they are under the terminal box.

(c) An additional thermocouple was introduced for each coil. This will permit a measure of the hot-spot temperature at the center of the coil.

Experience leads one to these conclusions:

(a) hardened glass-silicone insulators retain good electrical and mechanical properties even though exposed for 17 hours continuously to a temperature of 200°C with a passage of a 350-ampere current through the previously described coil;

(b) although at first estimate a magnet having hollow conductor coils appears more expensive, it is in the long run more economical than one with solid conductor coils.

Research With the 40-Inch Spiral-Orbit Spectrometer

Mu-Meson Positron Spectrum

The careful study of the high-energy positron spectrum from the decay of the μ-meson was completed. This is the combined effort of Mr. James Vedder and the writers.

Figure 7 illustrates schematically the experimental arrangement. For this experiment the electrically deflected 340-Mev proton beam was used. As listed in the previous quarterly report, various targets of different dimensions were mounted symmetrically about the magnetic axis. The π^+-mesons that were created by the interaction of protons with target nuclei and that stopped in the target decayed into μ-mesons and then into positrons. The positrons created in this way at the target were magnetically analyzed by the spiral-orbit spectrometer principle and detected by four plastic scintillation counters, in quadruple coincidence. The counting was delayed for approximately 2 μ seconds after the beam pulse. This counting was done by use of four tandem gates, each with a 2 μ sec width. In this way we could check the half life of the μ-meson, thus making sure that the positrons being detected were produced by μ-meson decays.

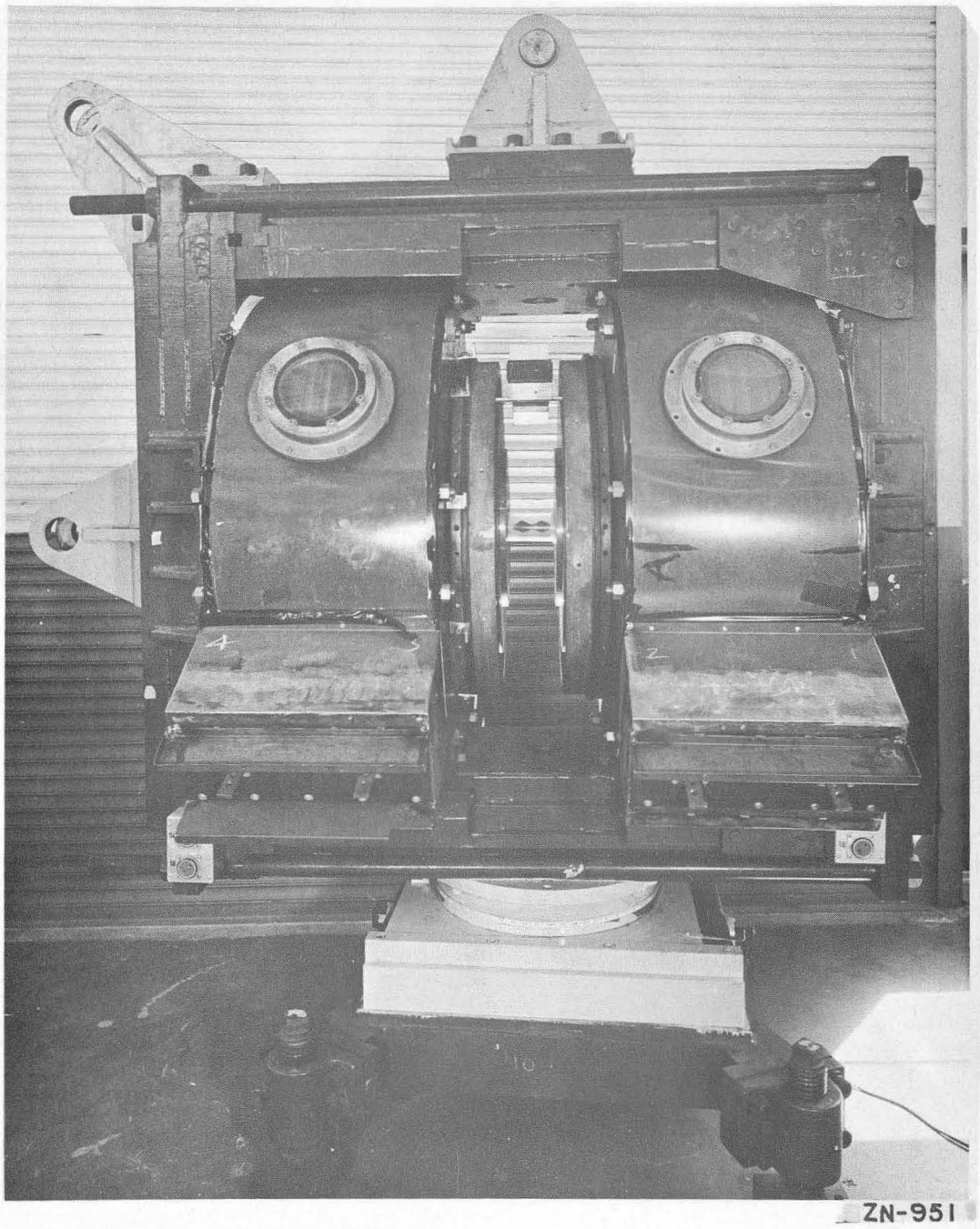
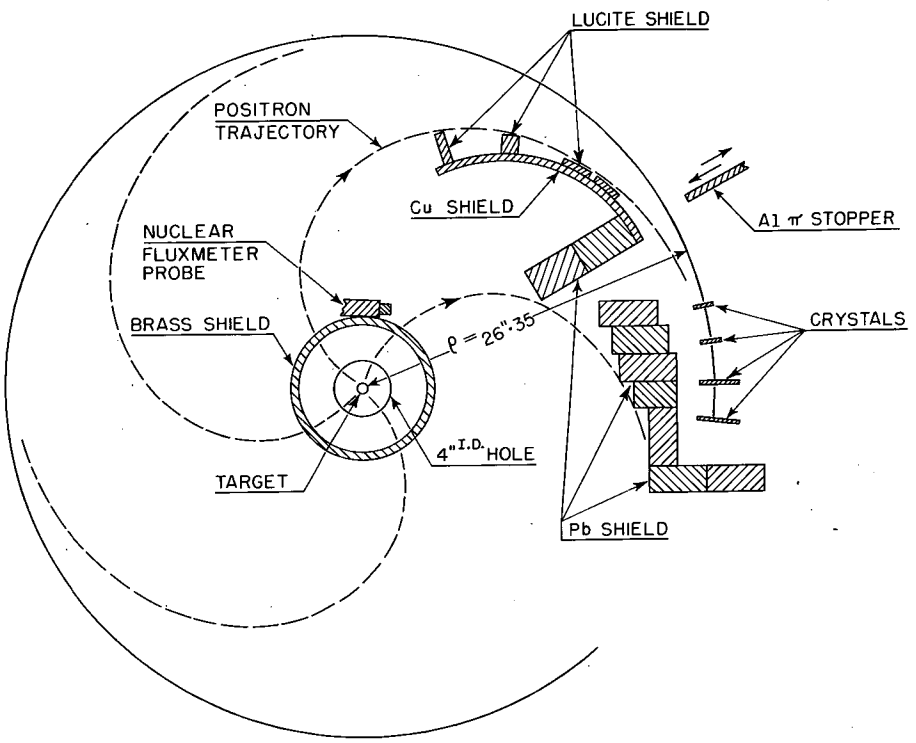


Fig. 6. Photograph of the spiral-orbit spectrometer. (22-inch)



SCHEMATIC OF DETECTION METHOD FOR POSITRON SPECTRUM FROM μ-e DECAY.

MU-7493

Fig. 7

The results are as follows:

(a) we could measure experimentally the finite cutoff at the maximum energy of the spectrum;

(b) the absolute value for this maximum energy was very accurately measured so that we could set the limit for the mass of the μ-meson to be not less than $207 \pm 0.8\ m_e$;

(c) this value was obtained independent of other measurements or assumptions such as are made for the previously established mass values (i.e., the validity of the assumed range-energy relation for mesons to accuracies better than 0.5%). As the absolute value for the μ-meson mass of our measurement is in good agreement with the previously reported values, the validity of the assumption of the range-energy relation for mesons to these high accuracies is verified;

(d) from this value of the μ-meson mass a value of the π^+ mass can be determined, as the ratio of the $\pi^+ - \mu^+$ range is accurately known. This value for the π^+ mass is $273.4 \pm 1.1\ m_e$;

(e) the general shape of the measured positron spectrum best fits the theoretical curve derived by Dr. Michel with the constant $\rho = 0.23$. The accuracy for this value has been estimated as $^{+0.03}_{-0.05}$.

Figure 8 shows the general shape of the spectrum as obtained from the measured data. The points measured in 1951 are also reproduced in this figure to indicate the reproducibility and also the improvement in accuracy of our present data.

Figure 9 shows how the value of $\rho = 0.23$ fits the data obtained from a 1-1/2-inch (outside diameter) carbon target.

Figure 10 shows in a scale greatly expanded in abscissa how the data from four different Be thin targets define the same energy maximum and the sharp cutoff in the neighborhood of this energy maximum.

Meson Scattering

π^+ Scattering by Protons and Carbon Nuclei

A test experiment to analyze scattered pions with the spiral-orbit spectrometer was successfully made. We believe this is the first measurement ever made on scattered pions that are analyzed by their momentum.

Figure 11 illustrates the method that was used. The external scattered 340-Mev proton beam was used to produce a reasonably mono-energetic pion beam

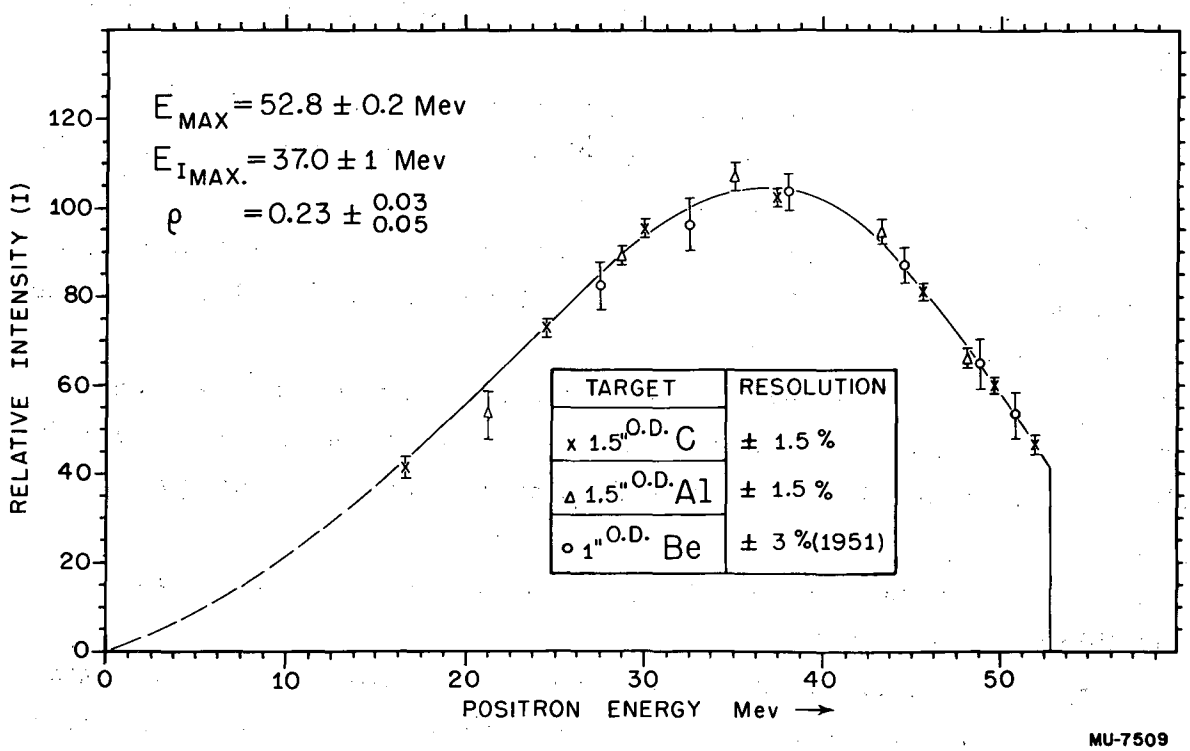

$E_{MAX} = 52.8 \pm 0.2$ Mev
$E_{I_{MAX.}} = 37.0 \pm 1$ Mev
$\rho = 0.23 \pm {}^{0.03}_{0.05}$
TARGET
RESOLUTION
x 1.5" O.D. C
± 1.5 %
Δ 1.5" O.D. Al
± 1.5 %
o 1" O.D. Be
± 3 %(1951)
RELATIVE INTENSITY (I)
POSITRON ENERGY Mev →
0
20
40
60
80
100
120
0
10
20
30
40
50
MU-7509

Fig. 8

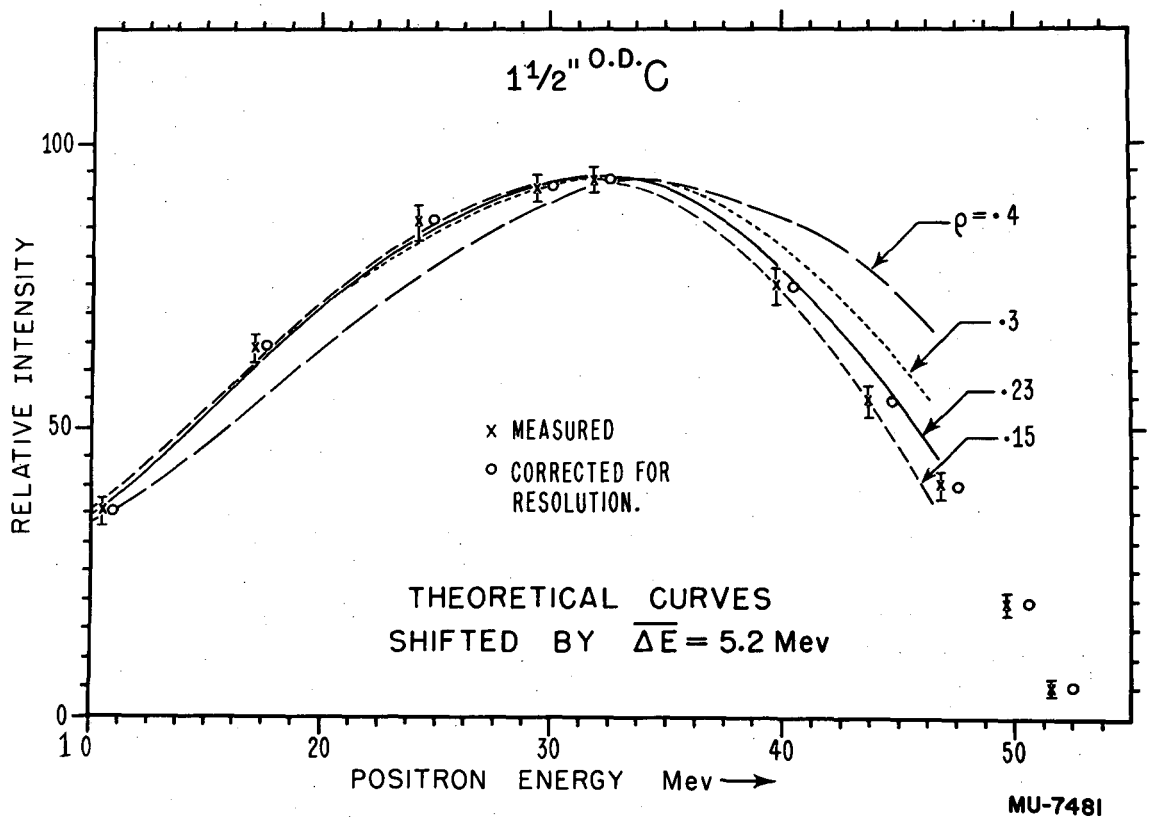

1 1/2" O.D. C
100
50
0
RELATIVE INTENSITY
ρ = ·4
·3
·23
·15
x MEASURED
o CORRECTED FOR RESOLUTION.
THEORETICAL CURVES
SHIFTED BY ΔE = 5.2 Mev
10
20
30
40
50
POSITRON ENERGY Mev
MU-7481

Fig. 9

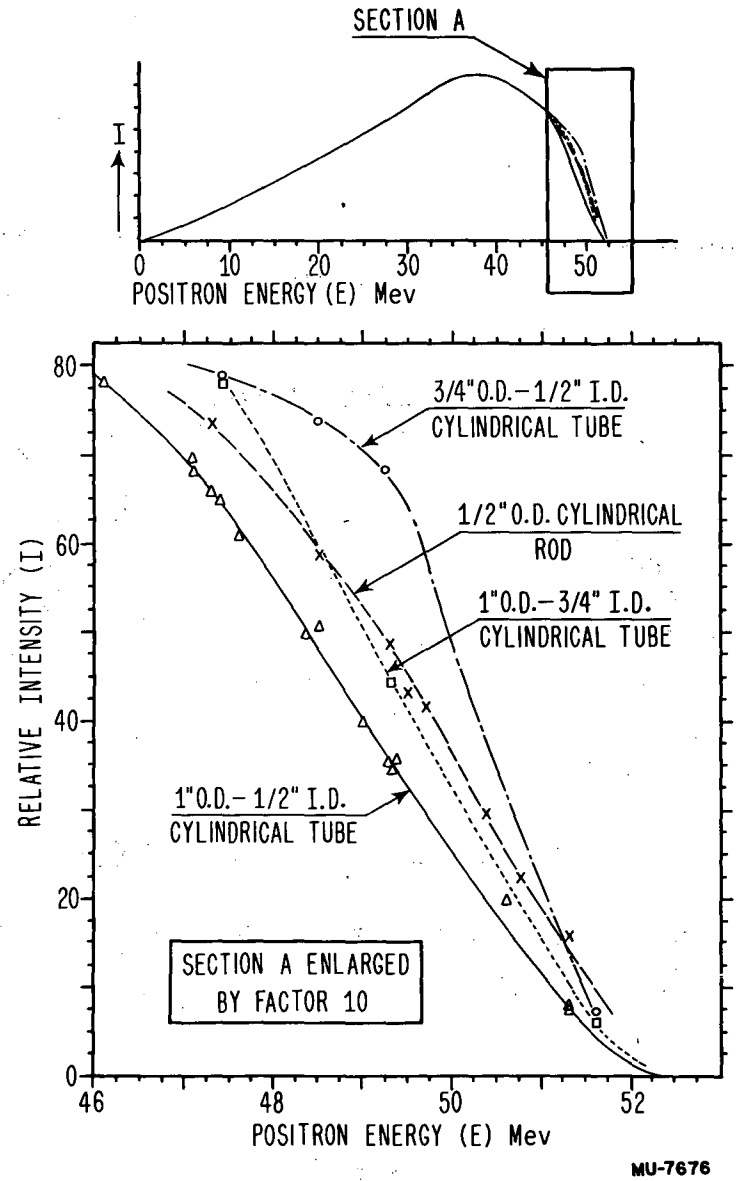
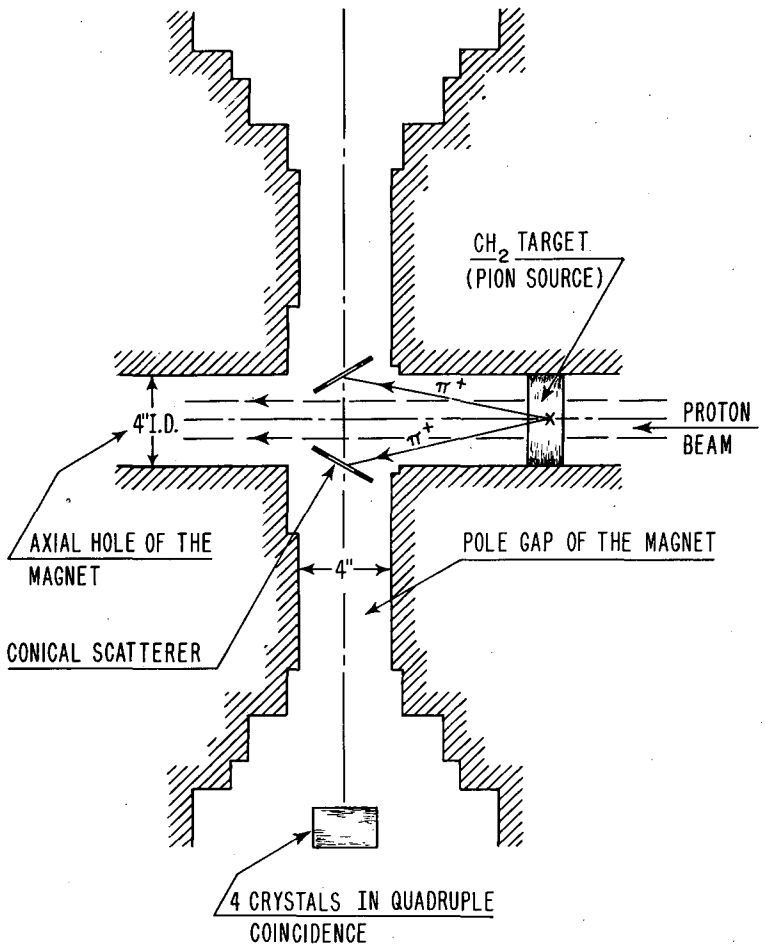

SECTION A
I
0
10
20
30
40
50
POSITRON ENERGY (E) Mev
80
60
40
20
0
RELATIVE INTENSITY (I)
3/4"O.D.-1/2" I.D.
CYLINDRICAL TUBE
1/2"O.D. CYLINDRICAL
ROD
1"O.D.-3/4" I.D.
CYLINDRICAL TUBE
1"O.D.-1/2" I.D.
CYLINDRICAL TUBE
SECTION A ENLARGED
BY FACTOR 10
46
48
50
52
POSITRON ENERGY (E) Mev
MU-7676

Fig. 10



SECTIONAL VIEW OF THE GEOMETRY FOR PION SCATTERING EXPERIMENT.

MU-7696

Fig. 11

when incident on a suitable thickness of $(CH_2)_n$ targets. These $(CH_2)_n$ targets were located inside the axial hole of the magnet. Pions emitted in a direction defined by the two cone tips of the scattering target (i.e., at angles $\theta = 7^\circ$ to $\theta = 20^\circ$, relative to the proton beam direction) were scattered by the conical scattering target that was mounted axially in the gap of the magnet. The conical target had a 2-1/2-inch (inner diameter) hole at the tip, to permit the proton beam to pass through the magnet. Pions scattered at $90^\circ \pm 10^\circ$ were detected by four plastic scintillation counters in quadruple coincidence that were placed at the stable orbit of the spiral-orbit-spectrometer. A $\left[CH_2 - C\right]$ subtraction method was adopted. Owing to the internal momentum of the nucleons in the carbon nucleus the pions scattered by hydrogen atoms had a lower energy at detection than those scattered by carbon. Figure 12 shows the results that were obtained for an incident pion energy $T_\pi \sim 58$ Mev, while Figure 13 shows the corresponding results at an incident pion energy $T_\pi \sim 48$ Mev. As indicated in the figures, we were able to resolve and identify the scattered pion peaks corresponding to hydrogen and carbon targets. The high peak at low pion energies is interpreted to be due to pions produced at the scatterer by the scattered protons and the carbon nuclei.

The present test proved definitely that the spiral-orbit spectrometer can be used very effectively for this type of experiment.

Intensity Test for Low-Energy Pion Flux

Another test was made which proved that we could obtain roughly a monoenergetic pion flux of about 5000 pions per square inch at the stable orbit in a pion energy interval of 15 Mev to 30 Mev. This flux is large enough to assure that we can do the proposed pion-attenuation scattering experiment at pion energies $T_\pi = 15$ Mev, 20 Mev, and 30 Mev within something like a normal week of cyclotron running time.

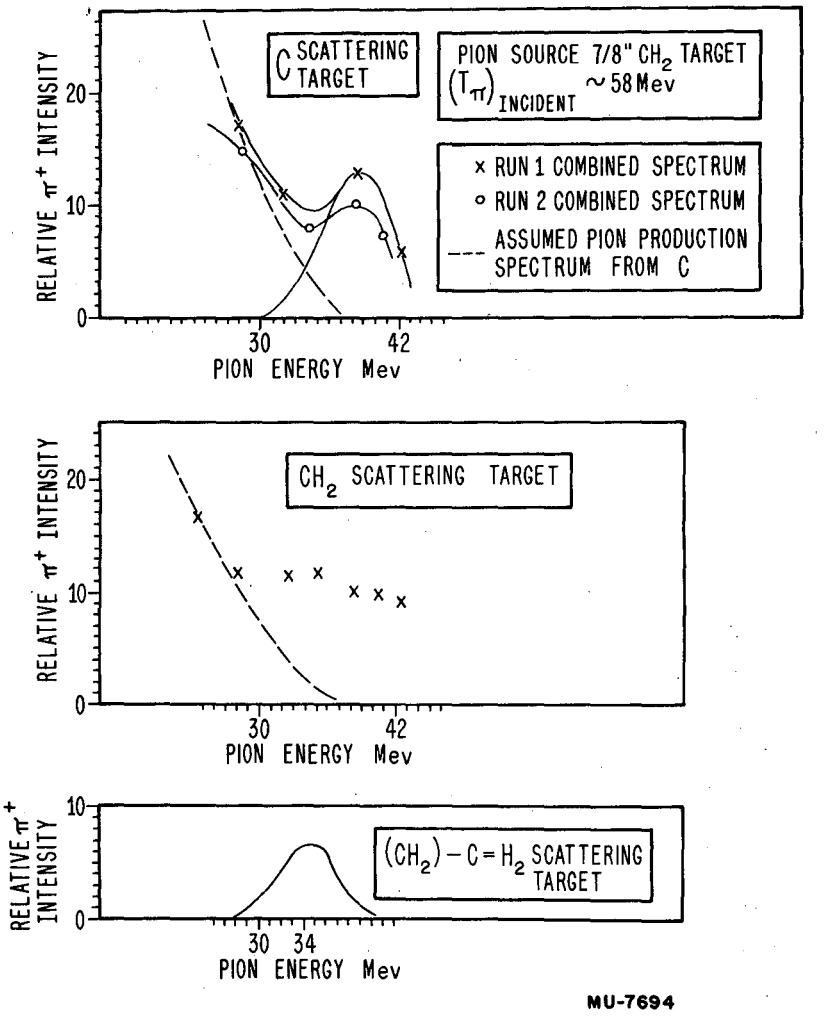

C SCATTERING TARGET
PION SOURCE 7/8" CH2 TARGET
(Tπ) INCIDENT ~58 Mev
× RUN 1 COMBINED SPECTRUM
○ RUN 2 COMBINED SPECTRUM
--- ASSUMED PION PRODUCTION SPECTRUM FROM C
RELATIVE π+ INTENSITY
PION ENERGY Mev
CH2 SCATTERING TARGET
(CH2) − C = H2 SCATTERING TARGET
MU-7694

Fig. 12

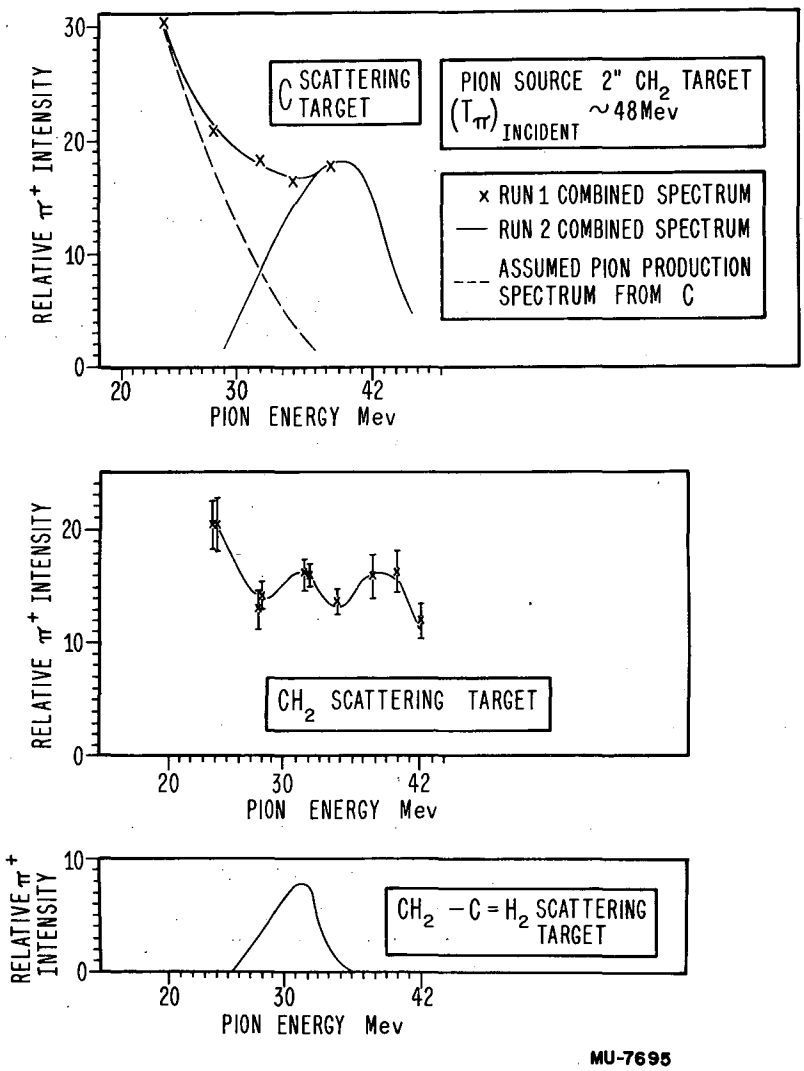

C SCATTERING TARGET
PION SOURCE 2" CH2 TARGET
(Tπ) INCIDENT ~48Mev
× RUN 1 COMBINED SPECTRUM
— RUN 2 COMBINED SPECTRUM
--- ASSUMED PION PRODUCTION SPECTRUM FROM C
RELATIVE π+ INTENSITY
PION ENERGY Mev
CH2 SCATTERING TARGET
CH2 −C = H2 SCATTERING TARGET
MU-7695

Fig. 13

FAST DEUTERONS FROM HIGH-ENERGY NUCLEONS BOMBARDING VARIOUS ELEMENTS

Wilmot Hess

The data from a run using 300-Mev protons and the E - dE/dx method of particle identification have been analyzed. The differential cross sections for deuteron production at 40° to the beam have been determined. For light elements (Li, C, and Al) the curve can be fit by $\sigma = k_1 A^{1.1}$. This is similar to the previously determined $\sigma = k_2 A^{1.30}$ found by using Hρ - Range. This would seem to identify the production mechanisms as being the Bransden indirect pickup. In addition to the deuterons, this time, a yield of tritons was observed, and cross sections were measured for them. Although the statistics are worse, the cross section still follows a law,

$$\sigma = k_3 A^{1.22}.$$

This would imply that these were also indirect pickup particles. The cross sections for both deuterons and tritons deviated from this A dependence above copper. There are various possible reasons for this. Electric-field stripping or Serber stripping inside the nucleus might be responsible; another possibility is that the surface area useful in producing deuterons is limited by the separation of the particles in a deuteron. That is, the radius of the pickup area on the nuclear surface is 2.5×10^{-13}, which is the average separation of the deuteron. When the nucleus has a larger surface than this, part of it is not useful in producing deuterons. This condition is reached at copper. A run has recently been completed using 300-Mev neutrons incident on the same elements as for the protons. Only the data for carbon and lead have been analyzed. The cross sections here are

$$\sigma n + C \rightarrow d^{(40^{\circ})} = 1.74 \pm 0.21,$$

$$\sigma n + Pb \rightarrow d^{(40^{\circ})} = 8.30 \pm 1.14.$$

Using these values and the cross sections for deuteron production when a proton beam is used to bombard carbon and lead, the fraction (F) of surface nucleons that are neutrons can be determined. The values obtained are

$$F \text{ for carbon} = 0.47 \pm 0.09,$$

$$F \text{ for lead} = 0.80 \pm 0.13.$$

These values are what one would expect from recent theoretical and experimental work. The nuclear surface should consist of more neutrons than protons, according to some current thought. This effect should be important for heavy elements such as lead, where the surface is a well-defined concept. For light elements the effect should essentially disappear.

CERENKOV RADIATION COUNTER AND π^0 DECAY PHENOMENA

Robert Squire and John Osher

We have completed tests on a Cerenkov counter designed for high-energy detection. An efficiency check at the synchrotron has shown a region of energy dependence of pulse height for electrons between 20 and 80 Mev, and a region of constant detection efficiency of 80 percent from 80 Mev up to the maximum energy available at the synchrotron. Shower production at higher energies ought to cause this efficiency to rise slowly, with no theoretical limit on the energy detectable. A report is being prepared on this subject.

Calculations concerning the alternate mode of π^0 decay have led to no theoretical explanation of the observation that cosmic ray π^0's have shown in emulsions an anomalous division of energy between electrons. Synchrotron-produced electron pairs in plates, as measured in the same energy region (100 Mev) by Peter Giles of this laboratory, show a very much weaker anomaly and, in fact, are almost in agreement with Heitler's curves for this phenomenon.

PHOTODISINTEGRATION OF THE DEUTERON

Dwight R. Dixon and Kenneth C. Bandtel

During the past quarter three short runs have been conducted to test and calibrate the dE/dx - range counter that is to be used in this experiment.

In a run using the 270-Mev neutron beam, a good high-voltage plateau for protons was found. It was discovered, however, that the separation between protons and mesons was not as clean as might be desired. Therefore the dE/dx counter was increased in thickness from 0.2 inch to 0.5 inch.

At the synchrotron, particles from a carbon target were observed. Except for some slight difficulty due to radiofrequency pickup from the synchrotron oscillator the over-all operation was satisfactory. Protons could be easily separated from mesons. Steps have been taken to reduce the radiofrequency pickup.

A run in the proton beam at the cyclotron provided information on the corrections that will have to be applied to data from the dE/dx - range counter. The counter was placed in a reduced-energy, low-intensity proton beam. It was found, for example, that approximately 20 percent of the incident 205-Mev protons failed to reach the ninth range channel. This is probably the largest correction that will have to be applied. Only 7.5 percent of the incident 96-Mev protons failed to reach the second range channel. Several experimental points were obtained, and they will be used to help work out a method for calculating correction for all

range channels with various absorber configurations.

Data obtained in this run provided a measure of the resolution of the dE/dx counter. The full width of the resolution curve at half maximum varied from 16.5 percent to less than 8 percent, depending on the energy of the incident protons.

A full-scale synchrotron run is scheduled for the first week in June.

GAMMA-RAY PAIR SPECTROMETER

Harlan Shaw and Charles Waddell

The 180° pair spectrometer was used at the synchrocyclotron to investigate the 15.2 ± 0.2-Mev gamma line seen from proton bombardment of carbon. Such a line was suggested in Richard Wildson's[1] experimental bremsstrahlung data from proton bombardment of carbon, but his method did not permit resolution of the line. Figure 14 shows this gamma line, superimposed upon bremsstrahlung, viewed at 90° to a carbon target bombarded by 140-Mev protons.

The error in energy assignment rests upon the accuracy of the wire-orbit method of energy calibration. This has been checked by observing the 17.6-Mev gamma line from Be^{8*}, and indicates that the energy error is within the above limits. A more accurate estimate of the energy can be made when the instrumental line shape has been calculated.

Relative values of the differential cross section from carbon at 90° in the laboratory system have been determined for proton energies of 30, 60, 100, 140, 250, and 340 Mev. Figure 15 presents a graph of the results. Absolute values have been roughly determined by monitoring the heat input to the target with a differential thermocouple set up along a heat leak from the target. This is related to the beam energy loss in the target, and hence, at a given energy, to the beam traversal through the target. The absolute efficiency of the pair spectrometer was calculated from geometry and pair-production cross sections, and corrected for multiple scattering and energy loss of the pairs in the converter.

The results for the differential cross section for carbon at 90° in the laboratory system with 30- and 340-Mev protons are 56 ± 15 and 3.3 ± 0.7 microbarns per steradian, respectively. The line is believed to arise from an excited state of the C^{12} nucleus. This is based upon the following evidence:

(1) The line is present with a carbon target for proton energies ranging from 30 to 340 Mev.

(2) It is not observed in proton bombardment of Be, B, or O.

(3) It is present in deuteron bombardment of B^{11} for deuteron energies ranging from 18 to 50 Mev.

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[1] Richard Wilson, Phys. Rev. 85, 568 (1952).

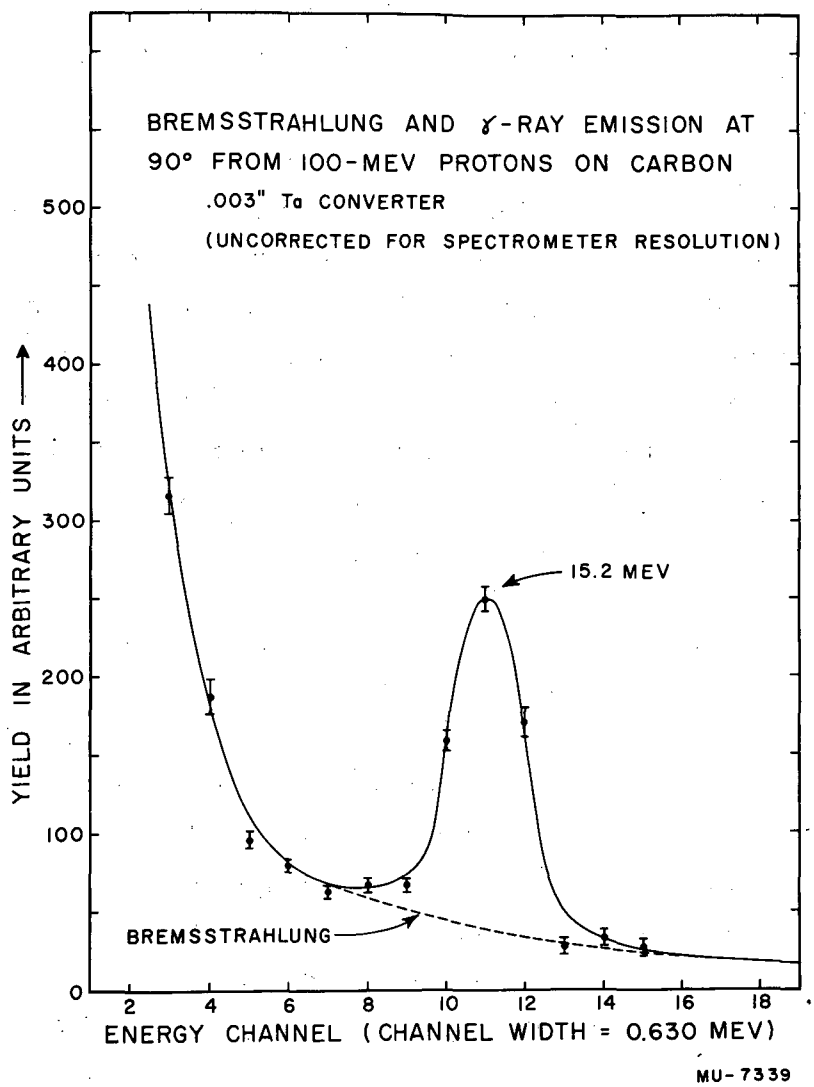
BREMSSTRAHLUNG AND γ-RAY EMISSION AT
90° FROM 100-MEV PROTONS ON CARBON
.003" Ta CONVERTER
(UNCORRECTED FOR SPECTROMETER RESOLUTION)
15.2 MEV
BREMSSTRAHLUNG
YIELD IN ARBITRARY UNITS
0
100
200
300
400
500
2
4
6
8
10
12
14
16
18
ENERGY CHANNEL (CHANNEL WIDTH = 0.630 MEV)
MU-7339

Fig. 14

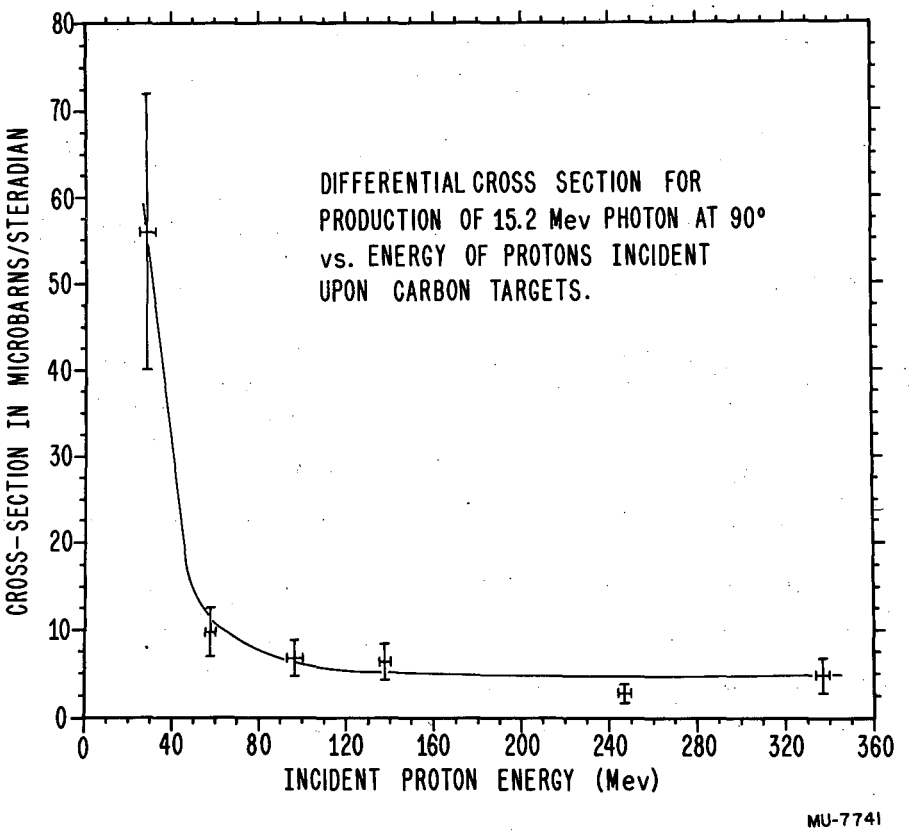
DIFFERENTIAL CROSS SECTION FOR
PRODUCTION OF 15.2 Mev PHOTON AT 90°
vs. ENERGY OF PROTONS INCIDENT
UPON CARBON TARGETS.
CROSS-SECTION IN MICROBARNS/STERADIAN
INCIDENT PROTON ENERGY (Mev)
0
10
20
30
40
50
60
70
80
0
40
80
120
160
200
240
280
320
360
MU-7741

Fig. 15

(4) It is not observed in deuteron bombardment of B^{10}.

Alpha bombardments have been tried on Be^9, B^{10}, and B^{11}, but low beam levels coupled with the contamination of the beam by large numbers of deuterons prevented reaching any definite conclusions.

Excitation of the C^{12} nucleus to the neighborhood of 15 Mev is not sufficient to produce neutron or proton emission, but disintegration into three alpha particles or into $He^4 + Be^8$ is energetically possible. The energy calibration of the spectrometer is sufficiently good to rule out the possibility of the line's being the familiar 17.6- or 14.8-Mev lines from Be^{8*}.

It seems reasonable to propose tentatively (as suggested in a private communication from the Cal Tech group) that the alpha disintegration may be considerably forbidden by isotopic spin considerations, which would be the case if this C^{12*} level were a T = 1 state. This allows dipole gamma emission in the transition to the C^{12} ground state[2]. Upon this basis the B^{12}, C^{12*}, and N^{12} would form the isotopic triplet.

The 15.09-Mev C^{12*} level listed by Ajzenberg and Lauritsen[3] may be the one listed here in question.

COMPARISON OF THE REACTIONS $p + d \rightarrow \begin{cases} \pi^+ + H^3 \\ \pi^o + He^3 \end{cases}$ AS A TEST OF CHARGE INDEPENDENCE

Kenneth C. Bandtel, Wilson J. Frank, and Burton J. Moyer

The latest results on this experiment were reported at the Washington meeting of the American Physical Society.

Owing to the 184-inch cyclotron shutdown, no further runs will be possible. A final report of the results is being prepared.

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[2] L. Radicati, Phys. Rev. 87, 521 (1952).

[3] F. Ajzenberg and T. Lauritsen, Revs. Modern Phys. 24, 321 (1952).

LIQUID-HYDROGEN GLASER BUBBLE CHAMBER

Luis W. Alvarez, Frank S. Crawford, Jr., Arnold J. Schwemin, M. Lynn Stevenson, and John G. Wood

Tracks have been photographed in a liquid-hydrogen bubble chamber of metal construction, with glass windows. Spontaneous eruption from the chamber walls did not interfere with the tracks. The chamber had a diameter of about 2-1/2 inches and a thickness of about one inch. At a chamber temperature corresponding to 70 pounds per square inch in the liquid hydrogen bath surrounding the chamber, the sensitive time for tracks is of the order of one to twenty milliseconds. Quantitative measurements on bubble growth rates vs time and temperature are in progress.

The successful operation of a chamber with metal walls and glass windows greatly increases the potentialities of this instrument. Some of the more obvious advantages over all-glass construction are in simplicity of construction, ease of obtaining optically flat windows, and rapid achievement of thermal equilibrium. In addition, there seem to be no essential limitations to prevent one from going to a large chamber. We are at present designing a chamber six inches in diameter and three inches thick, to be used as a research instrument. Experiments to determine the feasibility of expanding the chamber into a vacuum, rather than to one atmosphere, are in progress, with the hope that this will permit lower temperatures and pressures and make smaller demands on materials strength for large chambers.

GAMMA-RAY SCATTERING FROM LIGHT NUCLEI

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

Reproducible results in the elastic scattering of Co^{56} gamma rays off carbon have not as yet been obtained. The problem has been one of a 95% background, coupled with small electronic drifts of less than 1%. In order to subtract background in the presence of small drifts, automatic target insertion and removal has been installed. A large sodium iodide crystal has also been obtained and will be used in the experiment.

$p + p \rightarrow \pi^+ + d$ CROSS SECTION NEAR THRESHOLD

Frank S. Crawford, Jr., and M. Lynn Stevenson

New measurements on the reaction $p + p \rightarrow \pi^+ + d$ have been made, in an attempt to detect a tendency towards spherical symmetry in the differential cross

section, near threshold. The meson and deuteron were detected in coincidence, using scintillation counters and a liquid-hydrogen target. Differential cross-section measurements were obtained near 90° c.m. at incident proton energies of 313 Mev and 326 Mev. The results obtained were:

$$\frac{d\sigma}{d\Omega}(87^{\circ})_{cm\,313} = 4.7\,(1 \pm 0.06) \times 10^{-30}\ cm^2\ ster^{-1},$$

$$\frac{d\sigma}{d\Omega}(79^{\circ})_{cm\,326} = 8.2\,(1 \pm 0.05) \times 10^{-30}\ cm^2\ ster^{-1}.$$

These results can be compared with values at 0° to obtain the value of the spherically symmetric term "a" in the differential cross section, which is assumed to have the form $a + \cos^2\theta$. The values used for the differential cross sections at 0° were obtained by normalizing the relative excitation at 0° of Schultz et al. to our absolute cross section measurements near 340-Mev proton energies. The 0° excitation curve of Schultz et al. extends from 336 to 311 Mev. The results obtained by this method are that

$$a\,(326) = 0.30 \pm 0.04,$$
$$a\,(313) = 0.35 \pm 0.07.$$

These values do not differ perceptibly from those obtained near 340 Mev, nor are they essentially different from the values obtained at higher meson energies elsewhere. Thus, at meson c.m. energies of as low as about 12 Mev, the p-wave meson production still predominates in the determination of the angular distribution.

$p + p \rightarrow \pi^+ + d$ WITH POLARIZED PROTONS

Frank S. Crawford, Jr. and M. Lynn Stevenson

Marshak and Messiah[1] have pointed out that, if mesons are present in both S-wave and P-wave states in the above reaction, then it is possible to obtain, through interference between the S and P waves, an azimuthal asymmetry in the angular distribution, provided a polarized proton beam (or target) is used. Chamberlain, Segrè, Tripp, Wiegand, and Ypsilantis[2] have obtained a beam of polarized protons of approximately 320 Mev and having an estimated polarization of $P = 2\langle S_y \rangle = 0.75$, where y is the direction perpendicular to the plane of the scatter that produces the beam. Using this beam, we have made a preliminary measurement of the left-right asymmetry of the $p + p \rightarrow \pi^+ + d$ production, in the

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[1] Il Nuovo cimento, 11, No. 4, 1 April 1954.

[2] Phys. Rev. 93, 6, 1430 (1954).

plane perpendicular to the proton polarization, using coincidence detection of the meson and deuteron, and a liquid-hydrogen target. A positive effect has been observed, with a tentative result (L-R)/(L+R) = 0.18 ± 0.04. Here L and R refer to the direction of the produced meson, as seen by the incident proton. (The polarized proton beam is produced by a "left" scatter off a beryllium target, inside the cyclotron.) Checks were made to search for possible systematic errors resulting from improper alignment, effects of magnetic field on photomultipliers, and nonuniformity across the face of the plastic scintillator crystal, all with null results. In addition, the experiment was immediately repeated using the ordinary unpolarized scattered proton beam, which has been shown by Chamberlain et al. to be unpolarized. A null effect of -0.02 ± 0.06 was obtained in this over-all check. However, this latter test was seriously hampered by poor alignment of the unpolarized beam with respect to a 46-inch collimator immediately preceding the target. As a result, a highly asymmetric background, not present in the measurement with the polarized beam, had to be subtracted. In addition, insufficient data were obtained on the empty hydrogen container, which contributed from 5% to 20% of the full target effect. For these reasons the results must be considered tentative until they have been confirmed and the above-named experimental defects corrected. The experiment will be repeated in the near future to check these points.

RESONANCE EXCITATION OF DELAYED-HEAVY-PARTICLE EMITTERS

S. W. Kitchen

With the aid of the new transparent integrator (reported in the last quarter), the excitation curve of Al^{24} was reexamined. No evidence for the previously observed resonance was found. It is believed that the reproducibility of the resonance in the early measurements was an instrumental effect. Use of both the new integrator and the new UCRL Model 4 nonoverloading linear amplifier eliminated the spurious data.

A STUDY OF NEUTRON POLARIZATION

R. E. Donaldson and H. Bradner

Cyclotron runs have been made to investigate the polarization of neutrons obtained from the bombardment of carbon by a proton beam of known polarization. The polarized proton beam was obtained by scattering 340-Mev protons internally off Be at about 18°, and has been measured by Chamberlain et al. to be 65.0% ±

3.8% polarized and to have an energy of about 285 Mev.

Neutrons in coincidence with their quasi-elastic protons were recorded in forward and backward angles by means of large plastic scintillators with thin scintillators in front of them to discriminate against protons. At the same time the protons in coincidence with their quasi-elastic protons and the quasi + nonquasi protons were recorded. The latter were used to check the alignment by comparison with the Chamberlain results. These checked at all points. The results are presented in the curves shown on following pages. Runs were also made in the neutron beam with a similar setup. Neutrons were produced in a first scatter of 45° off a carbon target, and asymmetry of neutron yield was observed after scattering in a carbon second target. The results were:

Quasi-electric neutron

Neutron angle	$e = \frac{L-R}{L+R}$
20°	7.6 ± 2.9
30°	6.2 ± 3.0
65°	-6.4 ± 2.5

ELECTRON-NEUTRINO ANGULAR CORRELATION IN Ne^{19}

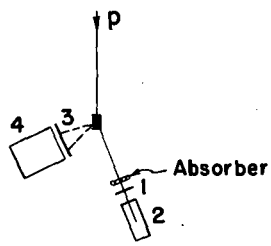
M. L. Good and E. J. Lauer

The differential pumping apparatus for the electron-neutrino angular correlation experiment, described in the last report, has been constructed and in large part satisfactorily tested. After completion of counter testing, this apparatus will be used in a linear accelerator run in an attempt to make the angular correlation measurement.

PROTON ANGULAR GAMMA CORRELATION

H. B. Knowles

Work is beginning on proton gamma correlation from nuclei excited by 32-Mev protons. There has been one run to date with a shielded sodium iodide gamma counter only, and the indication is that it will be possible to get a reasonable counting rate, but background problems are still troublesome.



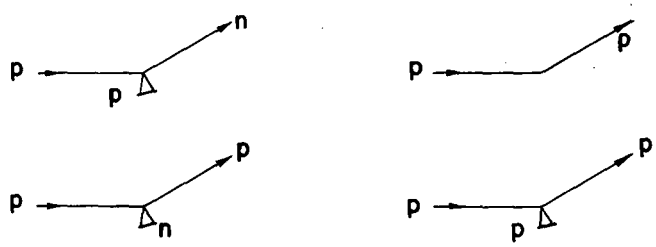
10^{-8} sec. coinc

12
34
14
23
2d3*
14d*

10^{-6} sec. coinc

12,23
14,34
14d,34
12,2d3

*6×10^{-8} sec delay to determine accidentals



MU-7497

Fig. 16

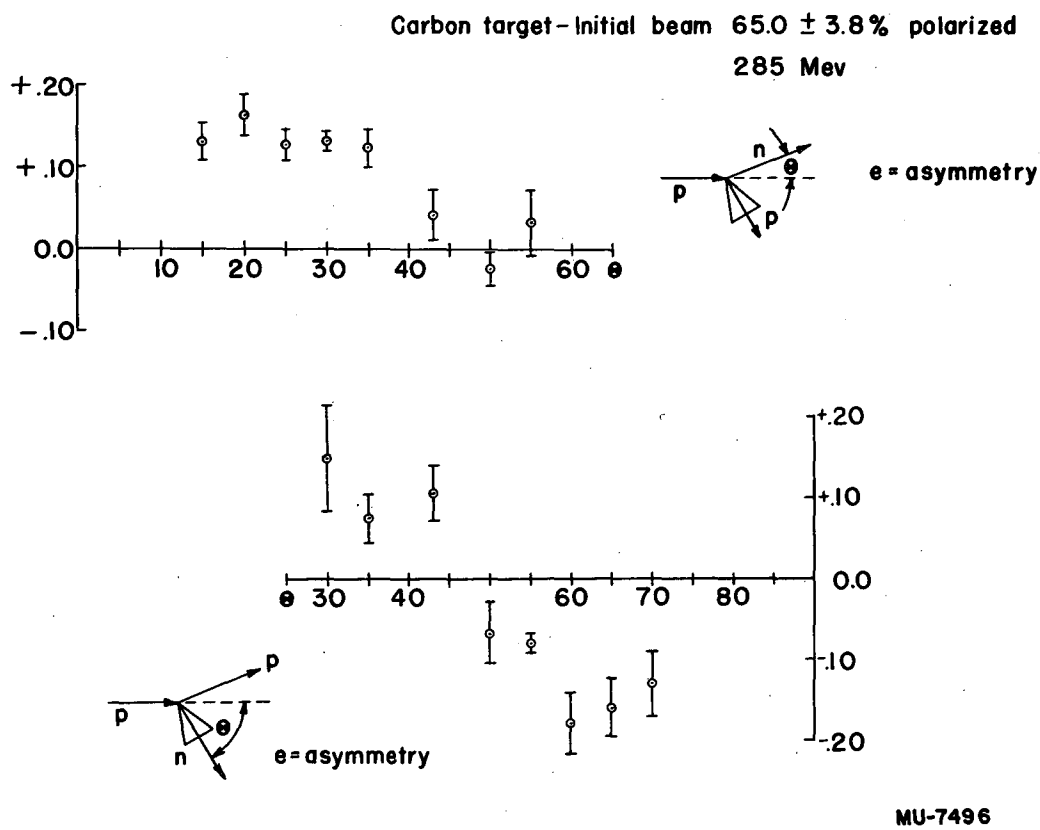

Carbon target - Initial beam 65.0 ± 3.8% polarized
285 Mev
+.20
+.10
0.0
-.10
10
20
30
40
60
θ
n
p
p
θ
e = asymmetry
+.20
+.10
0.0
-.10
-.20
θ 30
40
60
70
80
p
p
n
θ
e = asymmetry
MU-7496

Fig. 17

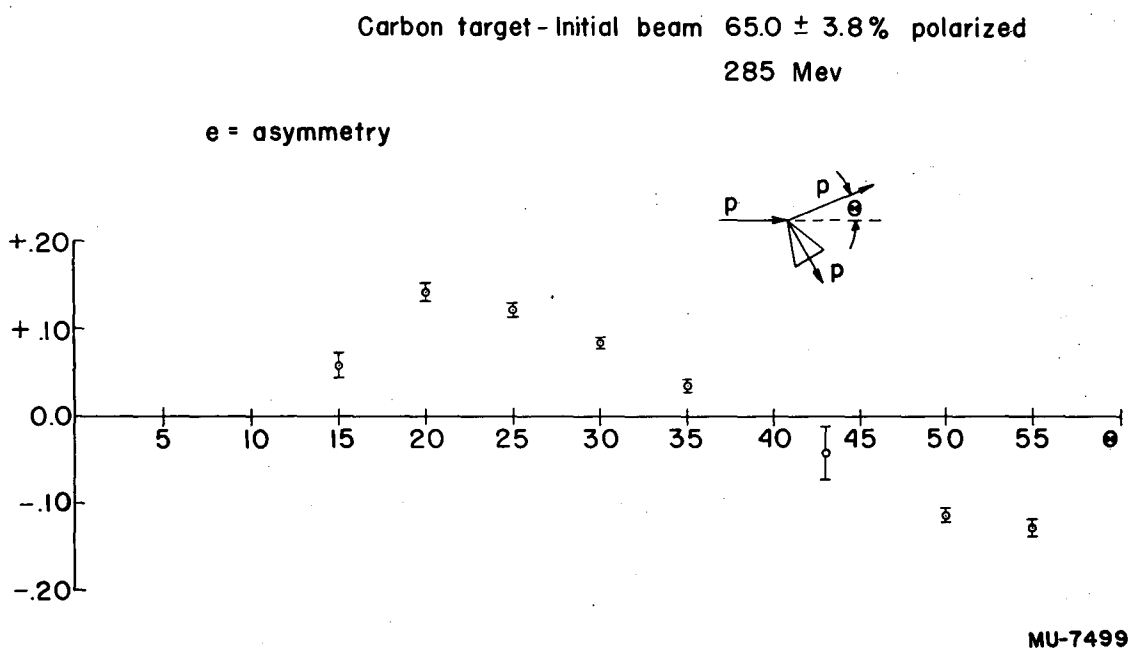

Carbon target - Initial beam 65.0 ± 3.8% polarized
285 Mev
e = asymmetry
+.20
+.10
0.0
-.10
-.20
5
10
15
20
25
30
35
40
45
50
55
θ
p
p
p
θ
MU-7499

Fig. 18

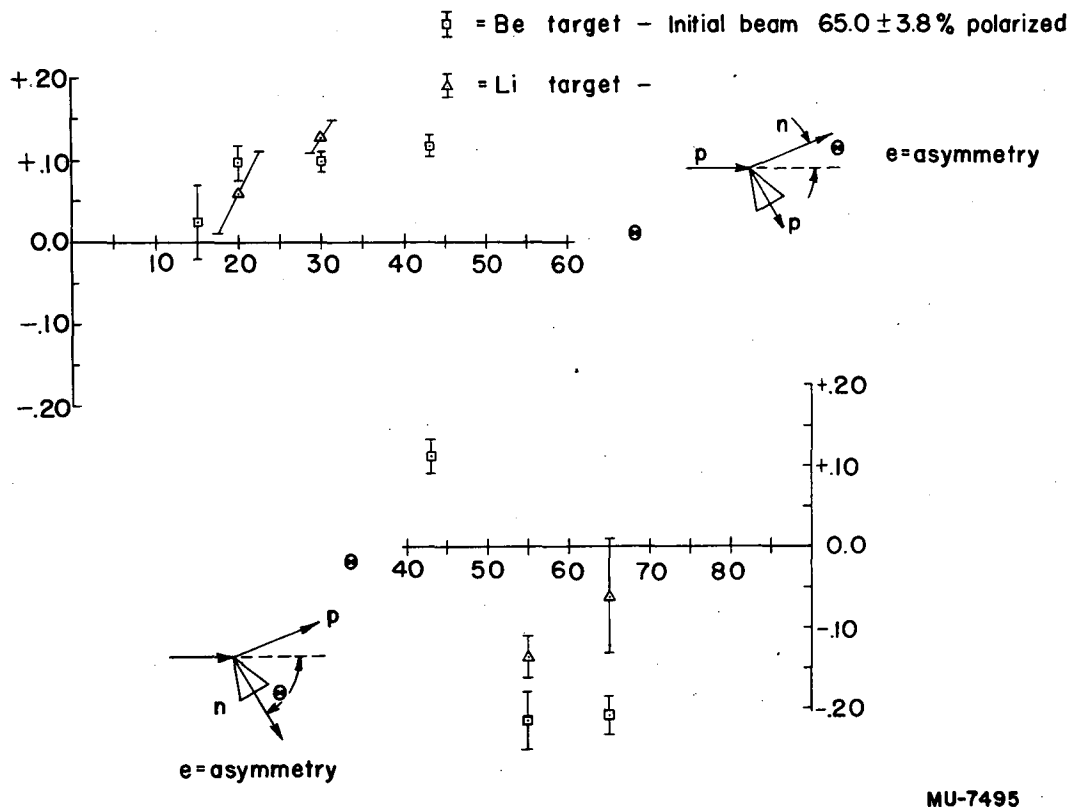

= Be target – Initial beam 65.0 ± 3.8 % polarized
= Li target –
+.20
+.10
0.0
–.10
–.20
10
20
30
40
50
60
θ
p
n
θ
p
e=asymmetry
+.20
+.10
0.0
–.10
–.20
θ
40
50
60
70
80
p
n
θ
e=asymmetry
MU-7495

Fig. 19

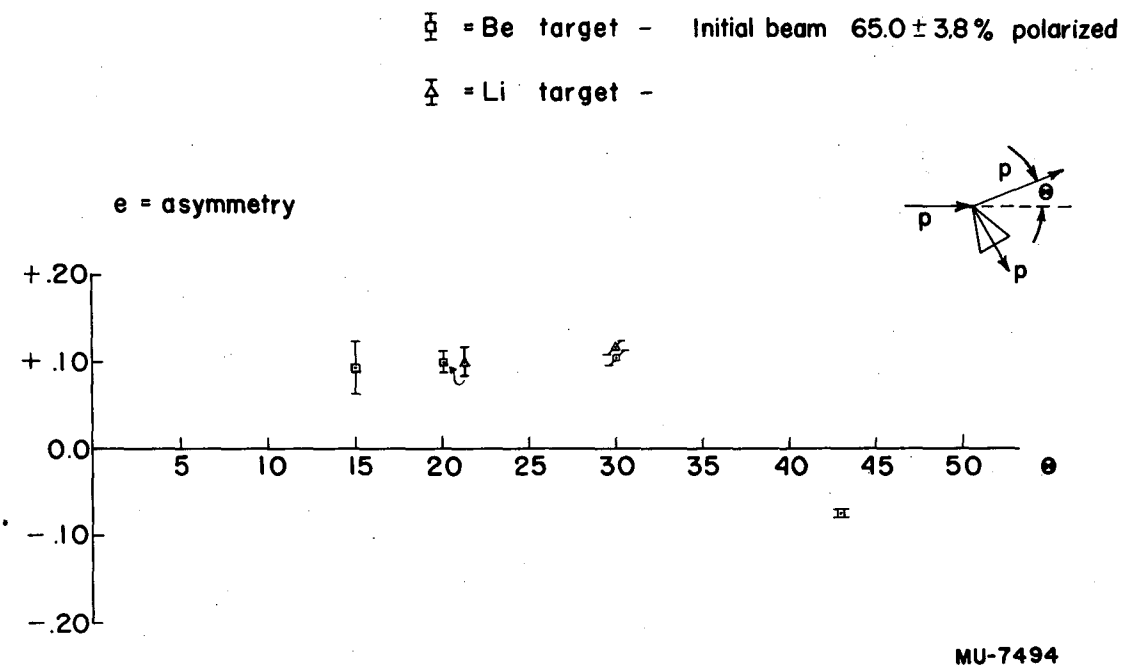

= Be target - Initial beam 65.0 ± 3.8 % polarized
= Li target -
e = asymmetry
+.20
+.10
0.0
-.10
-.20
5
10
15
20
25
30
35
40
45
50
θ
p
p
p
θ
MU-7494

Fig. 20

NUCLEAR EMULSION STACKS

Robert Birge, Leroy Kerth, Jack Merritt, Chaim Richman,
Jack Sandweiss, Don Stork, Stan Whetstone.

A reentrant cavity was built and installed on the top of the west tangent tank of the bevatron to hold nuclear emulsion stacks slightly above and behind a target that will be plunged into the beam from above. The design of this target and plunging mechanism was started.

Scintillation counter telescopes are being built to use as beam monitors during exposure of the emulsions. Consideration has also been given to monitoring the beam with a scintillator mounted directly on the target.

The technique for finding heavy mesons will probably consist of making a preliminary grain count on each entering track and following selected tracks until they stop, rather than scanning for stops. A preliminary test with emulsions 6 inches x 6 inches x 600 microns has shown that one can follow a track through from one emulsion to another with a line-up error of less than $\pm$ 20 μ.

A new Cooke microscope was received and a suitable stage will be designed for it.

FILM PROGRAM

Harry H. Heckman

Synchrotron Research

The study of the selective scattering of photons from the 330-Mev bremsstrahlung beam by various nuclei is continuing. The measurement of the gamma-ray energy spectrum from lead by multiple-scattering measurements of the electron pairs in G5 nuclear emulsion has been completed. Effort is now being placed upon the evaluation of absolute cross sections and the determination of the energy resolution for 6.14-Mev photons. The photons were obtained by bombarding CaF_2 with 657-kev protons.

Cyclotron Research

The experimental operations of exposing nuclear track emulsions to the spallation products from target nuclei under proton and alpha bombardment have been completed. These emulsions are now under initial scanning. The project includes the determination of cross sections and of angular and energy distributions of the spalls. The reaction ${}_3Li^7 + {}_1H^1 + {}_3Li^8$ and the electron pickup of Li^{8+++} are also being continued as a part of this program.

Other

Other research projects include the interaction of 380-Mev alpha particles and 30.8-Mev protons in G5 emulsion. A development program for pouring nuclear emulsion from the liquid gel form (obtained from Ilford Ltd.) has been initiated. Satisfactory completion of this project will largely eliminate the eradication processes that are employed to remove the latent images of the accumulated low-energy electron background.

CLOUD CHAMBER STUDIES

Wilson Powell

Four-by-Eight-Foot Cloud Chamber

New alcohol trays have been installed with electric soil-heating cable in the trays, providing accurate temperature control.

The cooling system has been rebuilt. The irrigation system previously used did not give equal temperatures on the bottom of the chamber. The present system keeps alcohol in contact with the bottom plate at all times and gives a very even temperature on the bottom plate.

Cloud-Chamber Windows

A technique has been devised for casting astrolite cylinders. This material is alcohol-proof and has been used in the 35-atmosphere chamber light windows. We have wanted to use alcohol in our expansion chambers for some time, making it possible to use a lower expansion ratio. Glass cylinder walls have been used in some chambers, but neither the 10-atmosphere nor the 22-inch chamber is adaptable to glass cylinders.

Since astrolite contracts approximately 5% on polymerizing, casting a cylinder raises many problems. A successful cast of a 13-inch-diameter cylinder was made in March, and after a failure a successful cast of a 23-inch-diameter cylinder was made.

The present technique requires that the core of the mold be removed as soon as the plastic reaches a jell state. This takes about 12 hours at room temperature, with the present proportion of liquid plastic, catalyst, and cold-setting promoter. The cast is then baked at 100°C for approximately 8 hours, after which the reaction has gone to completion and the cast is ready for machining.

THEORETICAL GROUP

David L. Judd

The investigation of Compton scattering on nucleons has been completed and a thesis on the subject has been written. (R. Huddlestone)

A comprehensive paper is being prepared on neutron polarization. (J. V. Lepore and W. Heckrotte)

The form of the nuclear potential used in the optical model (including the spin orbit potential) has been obtained in terms of the individual nucleon-nucleon scattering processes. (W. Heckrotte)

The fringing effects and aberrations of a magnetic spectrometer are under investigation in order to assist in the design of an instrument of relatively high transmission and resolving power. (D. Judd and S. Bludman)

Work on α-decay from spheroidal nuclei is in progress. At present, the numerical solution of the coupled differential equations describing the passage of the α-particle through the barrier is being approached. (B. Segall in collaboration with Dr. J. O. Rasmussen of the Nuclear Chemistry Group)

The investigation of the energy of the nuclear ground-state configuration as a function of shape is being continued. The consequences of the lack of a pronounced energy minimum for a symmetric deformation in certain nuclei are being looked into. (B. Segall)

Work on the high-energy neutron spectrum produced by protons impinging on complex nuclei is being continued. The spectrum from an α-particle target has been obtained and is ready for numerical evaluation. (E. Vaughan)

The intermediate coupling approximation for meson-nucleon scattering described in Report No. UCRL-2341 has been extended to the neutral pseudoscalar field, and agreement with perturbation theory and strong-coupling theory in the appropriate limiting cases has been achieved. Numerical calculations in the intermediate region are being carried out. (B. Fried and R. J. Riddell, Jr.)

A paper is being prepared on the statistical treatment of high-energy events. An attempt is being made to utilize the methods developed in this paper to interpret the data on meson production obtained at Brookhaven. (J. V. Lepore, M. Neuman, and R. Stuart)

A UCRL report on the electrostatic stripping of deuterons produced in pick-up process has been completed. (R. Stuart)

Since the discovery that the bevatron is out of level, extensive surveys have

been made to determine the errors in elevation and angle of the magnet sectors. These measurements are being analyzed to determine their effect on the beam and to establish a method of correction. The main harm seems to be a loss of about two inches of vertical aperture, which although not disastrous, is serious enough to require correction. (L. Smith)

The Tomonaga approximation for the pseudoscalar field interacting with nucleons in the strong coupling limit is being investigated. (K. Curtis)

The formal methods recently employed in field theory have been applied to the Taylor-Karman theory of turbulence. The relatively involved relations between the various correlation functions become quite perspicuous in this form. The possibility of devising different approximations to these equations is currently being investigated. (M. Neuman)

A formulation of the Tamm-Dancoff method which is mass-renormalized to all orders has been developed. This is part of a study of mass renormalization in intermediate coupling theory. (H. Stapp)

A paper dealing with a covariant approximation scheme for the Green's functions equations of field theory has been written and submitted for publication. Rough preliminary calculations tend to agree with experiment in meson-nucleon scattering. (R. Arnowitt and S. Gasiorowicz)

A preliminary examination of the problems of renormalization in connection with the above scheme has been started. (R. Arnowitt, S. Gasiorowicz and S. Bludman)

ACCELERATOR OPERATION AND DEVELOPMENT

BEVATRON OPERATION

I. Injector

February 1953 - April 1954

Bruce Cork

Introduction

The bevatron requires an intense source of high-energy protons. The machine should accept monoenergetic protons for a duration of approximately 500 microseconds once every 6 seconds. To satisfy the requirements of small loss due to scattering by the gas in the accelerating chamber, a 9.9-Mev linear accelerator has been built and operated.[1]

A 500-kilovolt Cockcroft-Walton generator is used to inject 2 ma peak proton current into the linear accelerator. Focusing grids intercept approximately one-half of the injected beam. Additional losses, including radial defocusing and acceptance phase angle, result in a peak accelerated beam of 50 microamperes. The energy spread has not been measured but an upper limit is less than ±30 kev.

The Cockcroft-Walton Generator

The original model of the cascade rectifier high-voltage generator was operated with the filaments and plate voltage supplied by two 60-kc oscillators. The unit was insulated by using oil-filled containers and cooled by circulating the oil. It was subsequently replaced because it was too complex for this application.

Since it is desirable that the stored energy of the high-voltage terminal be sufficient so that its potential remains nearly constant during the 500-microsecond pulse, larger coupling condensers should be used. This allows the plate voltage supply frequency to be lower. The generator now consists of 12 pairs of RCA 8013A air-cooled rectifier tubes arranged on lucite shelves, Fig. 21. The filaments of the rectifier tubes are heated by 60-kc power coupled through a ferroxcube-core cascade transformer. The plate voltage is supplied by an 800-cycle motor generator and is coupled through the pyranol condensers, each rated 20 kv, 0.25 microfarads.

The ion source and power supplies are located inside a duraluminum shell 4 feet on a side and 6 feet long. The present source is a cold cathode, axial type,

1. Bruce Cork, The Bevatron 9.9-Mev Proton Linear Accelerator, UCRL-2385, June 1954.

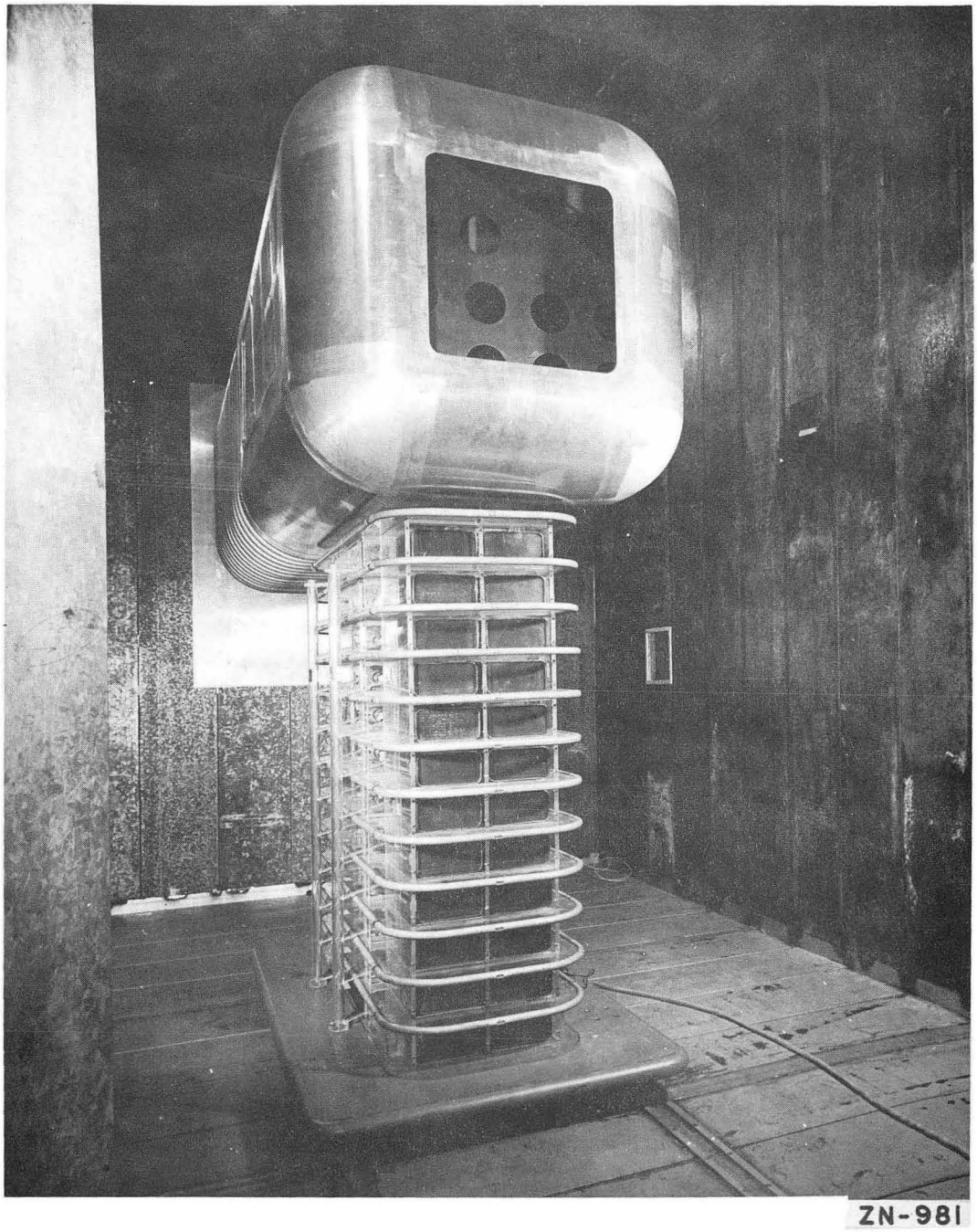


Fig. 21. The 500-kilovolt Power Supply and High-Voltage Shell.

arranged to give 2 milliamperes of protons with 35 kev energy. The proton beam is accelerated along the horizontal accelerating tube which is 6 feet long and consists of 27 sections. The insulating sections are made of zircon and the accelerating electrodes are made of spun stainless steel.

The voltage is stabilized by obtaining a signal from a 2000-megohm resistance divider. This signal is used to regulate the field of the 800-cycle generator. Also, a signal can be applied to the grid of a 304 TH voltage-regulator tube arranged to raise of lower the potential of the entire stack of Cockcroft-Walton coupling condensers. This regulator has a response time of 50 microseconds, thus corrections can be made during the 700-microsecond beam pulse.

The Linear Accelerator

The proton linear accelerator has a cylindrical cavity 18.2 feet long and 42-1/4 inches in diameter. It operates in the axial electric (0, 1, 0) mode at 202.5 megacycles. The protons are injected along the axis and are accelerated as they cross the gaps between each of the 42 drift tubes, Fig. 22. The spacing between drift tubes is made equal to $\beta\lambda$ where β, the ratio of the velocity of protons to the velocity of light, is 0.030 at injection and 0.144 at the exit of the linear accelerator.

The entrance aperture of the accelerator is 1/2 inch in diameter, the exit aperture is 3/4 inch in diameter. To reduce the radial component of velocity of the proton beam, focusing grids are used. These are 0.002-inch-thick tungsten ribbons mounted on edge at the entrance of each drift tube.

The resonant cavity is mounted in a cylindrical vacuum tank 20 feet long and 54 inches in diameter. The tank is evacuated with a 20-inch-diameter mercury diffusion pump.

The peak power of 500 kw required to excite the cavity is supplied by three Eimac type 3W 10,000 A3 triode oscillators. An Eimac 4W 20,000 tetrode oscillator is now used as a preexciter. These oscillators are being developed by a group working with Jack Franck.

Auxiliaries

To reduce the divergence of the proton beam, four magnetic quadrupoles[2] are located at the exit of the linear accelerator. These require a gradient of 700 gauss per inch and a power of 80 watts for maximum beam through the deflection

2. Bruce Cork and Emery Zajec, Quadrupole Focusing Lenses for Charged Particles, University of California Radiation Laboratory Report No. UCRL-2182, April, 1953.

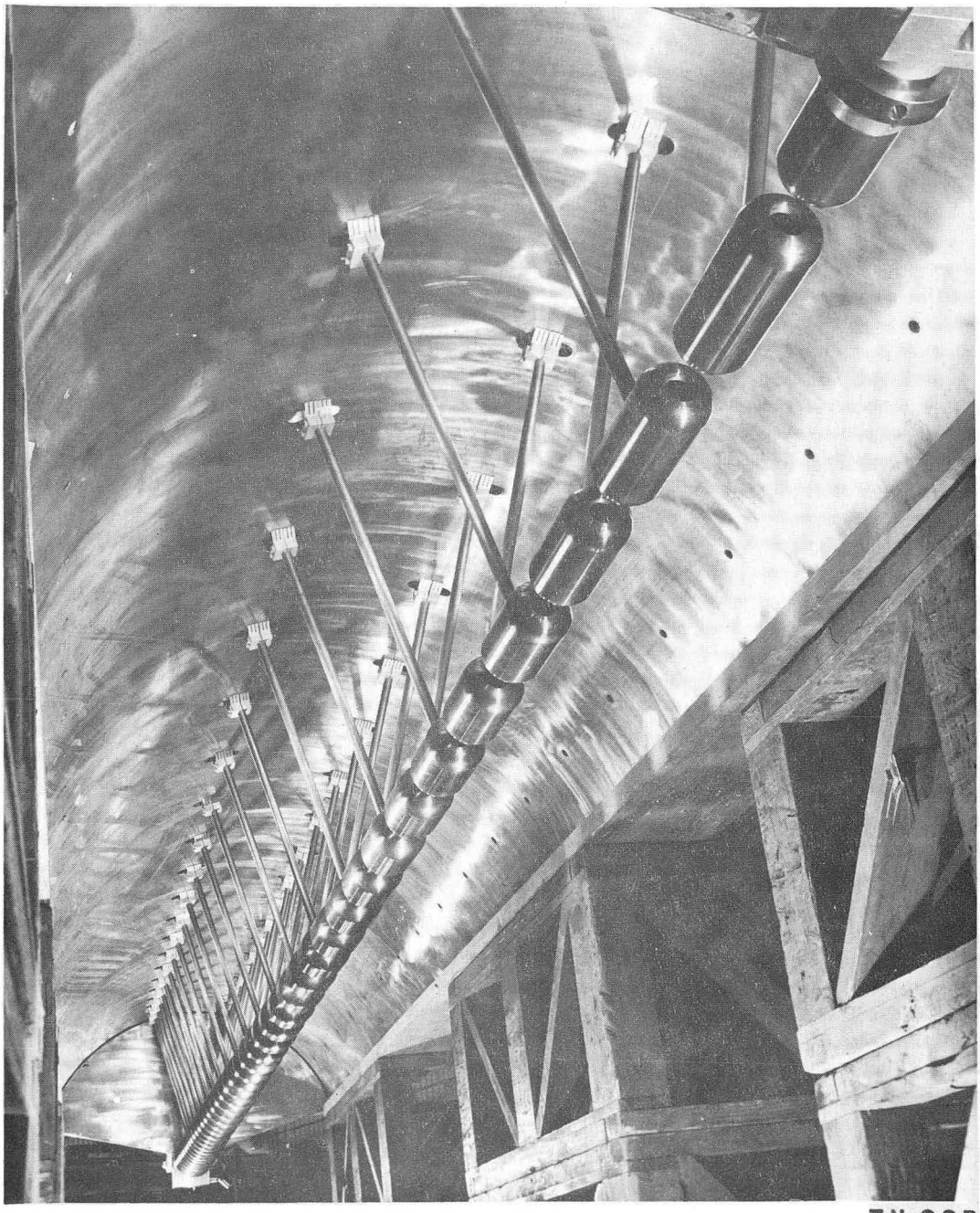


Fig. 22. Axial Drift Tubes, Looking Toward the Entrance End.

plates at the entrance to the bevatron.

The electrostatic inflector deflects the proton beam through an angle of 35°, with a radius of curvature of 18 feet. The electrodes are 132 inches long, spaced with a gap of 7/8 inch, and require a potential difference of 78 kv to deflect the 9.9-Mev beam.

Operation

The 0.5-Mev accelerator was first operated during February 1953. Since the stored energy of the Cockcroft-Walton generator is so great, 2500 joules, no attempt has been made to spark it to the ground. Surge resistors have been installed to limit the discharge current to 80 amperes, but the supply has never sparked directly to the ground. On several occasions the pressure in the accelerating tube has inadvertently been allowed to become great enough so that a glow discharge occurred. The accerating tube was not damaged and no difficulty has been encountered in holding voltage.

The linear accelerator has been operated since May 1953. Although some initial sparking occurred at high level, no difficulty was encountered in building up radiofrequency voltage across the drift tubes. After a few hours' operation at slightly higher than optimum voltage gradient in the cavity, sparking is very rare at the optimum gradient.

During the first few months of operation the accelerator was used as a source of 9.9-Mev protons for proton-proton scattering[3] and proton-alpha scattering experiments.[4] The machines have been very reliable, with approximately 50 hours' operation each week. The vacuum tank and cavity had not been opened for the first year after initial operation. Recently the cavity was opened to install new coupling loops for the new preexciter.

Measurements show that the optimum injected energy from the Cockcroft-Walton generator is 460 kv, rather than the design value of 450 kv. If the injection energy differs from the optimum value by ± 40 kv, the accelerated beam current is reduced to half value.

The energy of the accelerated protons was measured by scattering from helium through an angle of 30°. Measurements were made of the amount of aluminum

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3. Bruce Cork and Walter Hartsough, Proton-Proton Scattering at 9.7 Mev, University of California Radiation Laboratory Report No. UCRL-2373, October 1953.
4. Bruce Cork and Walter Hartsough, Elastic Scattering of 9.7-Mev Protons by Alpha Particles, University of California Radiation Laboratory Report No. UCRL-2590, May 1954.

absorber required to stop the scattered protons. The measured energy was 9.88 ± 0.1 Mev, and the energy spread was less than 0.1 Mev. Range straggling limited the accuracy of measurement of the energy spread to the above value.

The electrostatic deflection plates make the 35° inflector a very good energy selector. It is observed that twice as much beam strikes the central 1/4-inch strip of the faraday cup as strikes each 1/4-inch-wide strip on either side of the center. From this it is calculated that the energy spread is less than ± 32,000 volts.

During typical operation, the Cockcroft-Walton accelerator will give 2.0 milliamperes peak of accelerated protons. With this injected beam current, the accelerator will accelerate a peak beam current of 50 microamperes. The transmission of the focusing grids is estimated to be 50%. Assuming no losses due to radial defocusing, the acceptance phase angle is then 20°. Measurements have been made to determine the synchronous phase angle by measuring the threshold value of the rf voltage on the drift tubes for full-energy acceleration. The ratio of this voltage to the value for maximum beam is approximately equal to the cosine of the synchronous phase angle. This measurement gives a synchronous phase angle of 25° or an acceptance phase angle of approximately 75°. Thus, an additional loss--probably due to radial defocusing--causes a further loss to approximately one fourth of the expected current.

Some work is being done on a buncher to increase the acceptance phase angle. Also, work is being done on an improved ion source.

II. Operation

February - May 1954

E. J. Lofgren

Introduction

A description of the Bevatron is not necessary here; the main features of the structure are evident in the figures. Figure 23 is a wide angle photograph taken from above the straight section which contains the inflector. Figure 24 is a schematic plan view which shows the relationship of the main parts. Figure 25 is a simplified cross section through the magnet. Note that the magnet pole tips are inside the vacuum tank and that the access space provides a place for the installation of target mechanism.

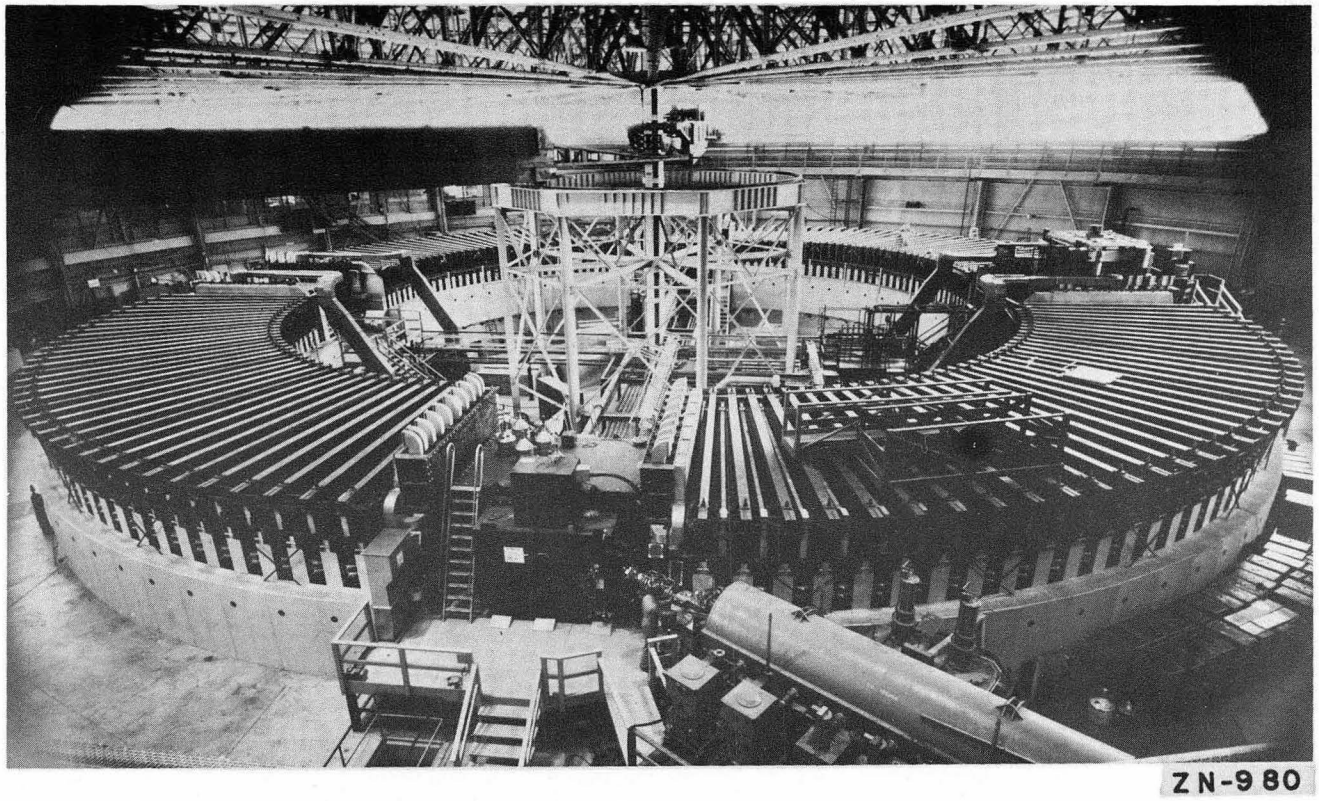

Fig. 23. General View of the Bevatron. Injector in the foreground.

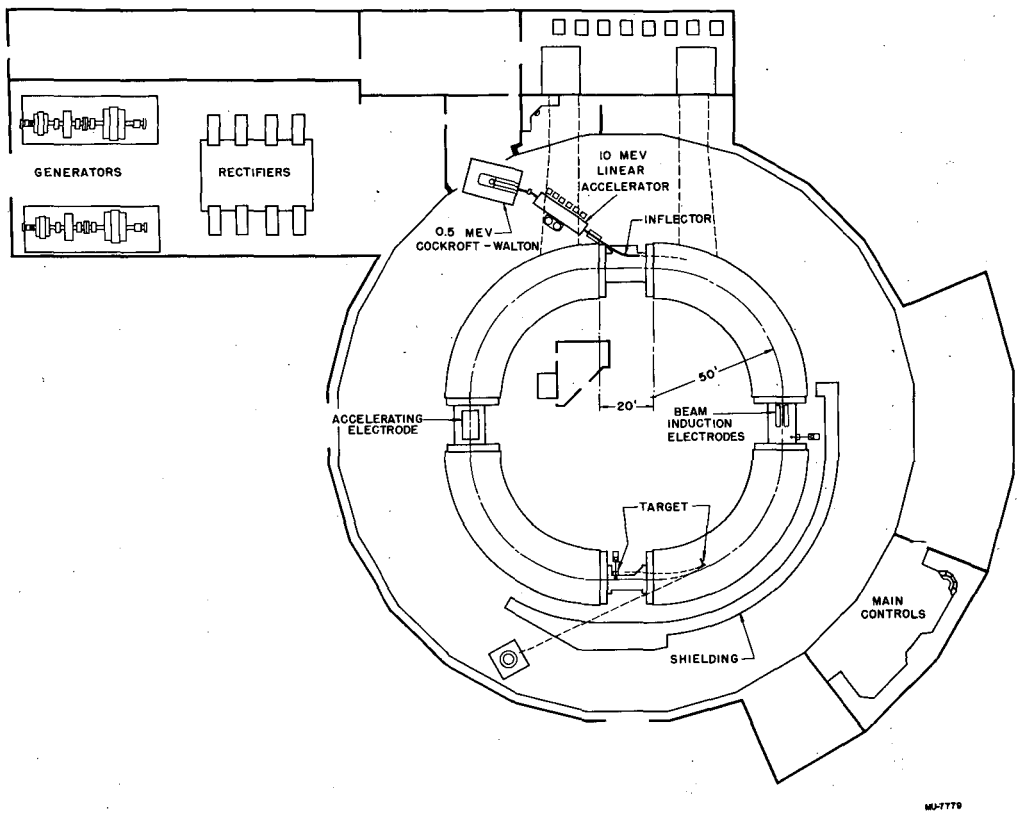

Fig. 24. Schematic plan view.

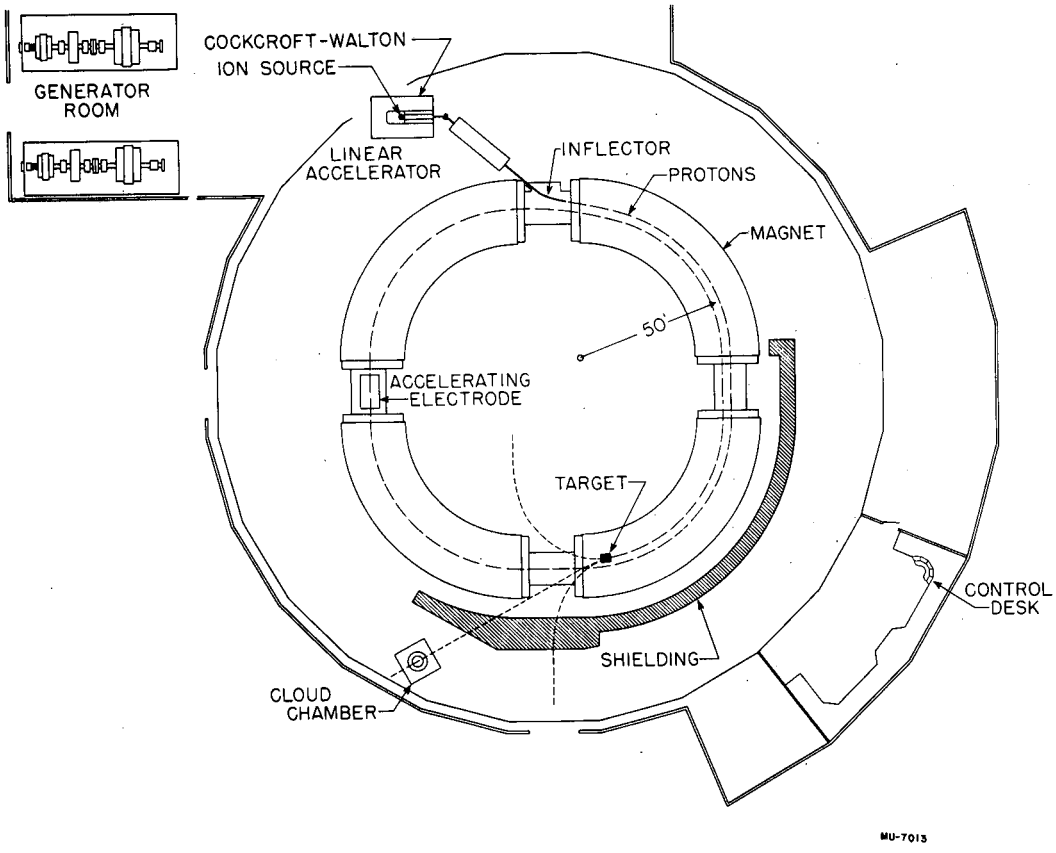

Fig. 25. Cross section.

On February 2 beam was injected into the bevatron with a static magnetic field. It was detected on probes 180° around the machine. In subsequent steps multiple turns were observed, then the experiment was repeated with a dynamic magnetic field, and finally the accelerating rf was turned on. Acceleration for a few milliseconds was accomplished on February 15. A succession of improvements in timing, frequency control, detection instrumentation, and operating technique was reflected in increasing beam energy until a maximum of 6.1 Bev was reached on April 1. A week later a short circuit occurred in the stator windings of one of the generators, and there has been no operation since then.

Operation

The accelerated beam was detected on a scintillator-photomultiplier probe inserted radially into one of the straight sections from the inside of the magnet. (See Fig. 24) The observed general characteristic, as shown in Figure 26, is a continual loss of beam during acceleration and a final burst which spirals into the probe about ten milliseconds after the accelerating rf is turned off. Induction electrodes, which pick up a signal from the circulating bunch of protons, were also used. This is an extremely useful signal because it does not require interception of the beam. However, the steady attrition of the beam made this signal useless for energies higher than 0.35 Bev.

Nuclear emulsions have been inserted into the beam, and from them it is possible to estimate that there are 10^5 or 10^6 protons per pulse.

No proven explanation for the beam loss has been found. A careful study of the rf system was just getting under way at the time of the generator failure. Some improvement had been made by diminishing an extraneous modulation which was found on the rf at the power amplifier. However, the attrition was still greater than expected by a factor of 100, and the possibility of troubles other than rf was actively investigated. The vacuum is about 10^{-5} mm and with injection at 10 Mev only about 20 percent of the beam should be lost because of scattering. The alignment of the magnet was also checked, with interesting results, as given in the next section.

Magnet

When the magnetic field was measured in October-November 1953, the median plane of field coincided with that of magnet to within 0.1 inch. During operation, however, it was shown by the use of aperture-defining vanes that the beam

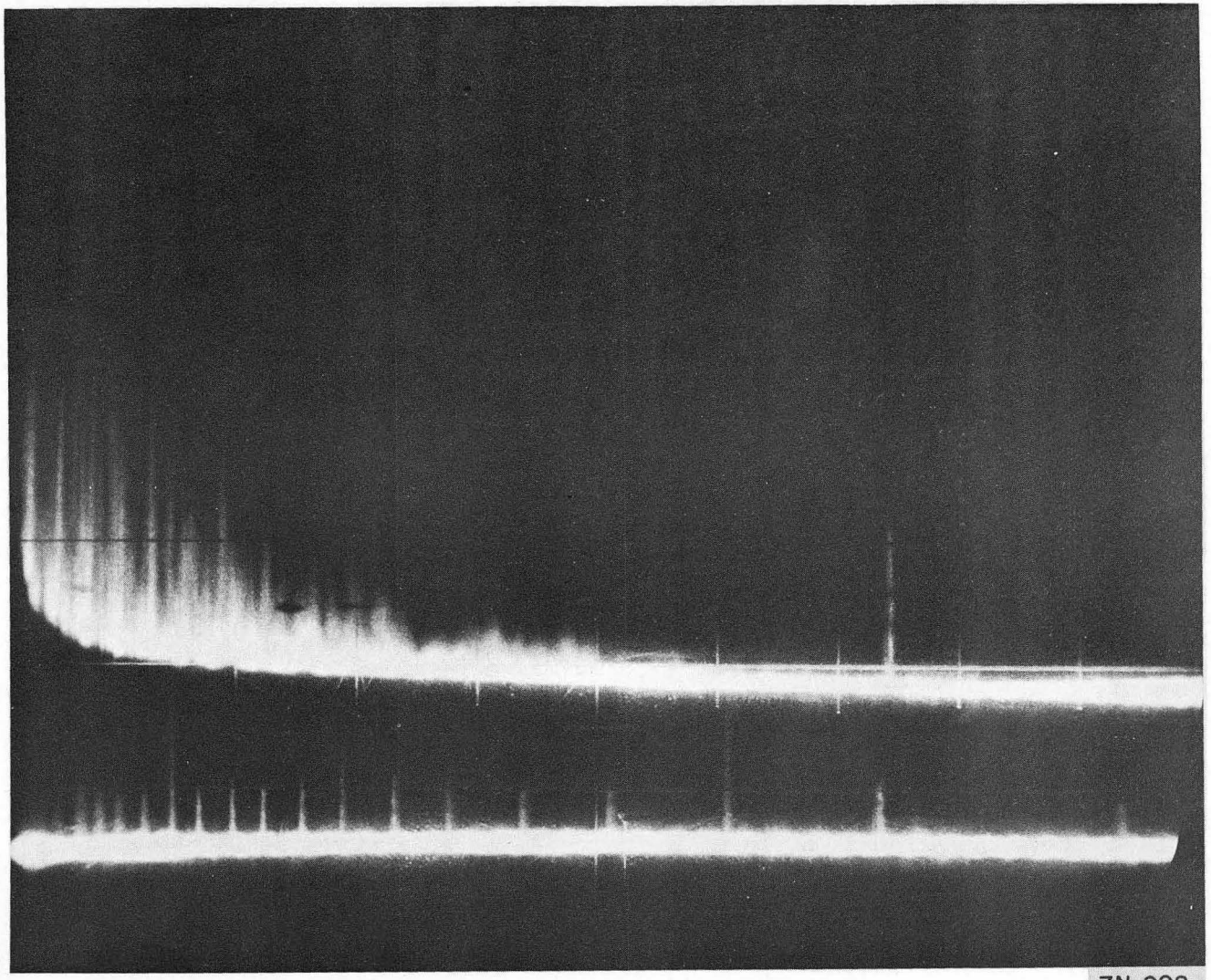

Fig. 26. The upper trace shows the beam intercepted on a scintillator-photomultiplier probe. The left portion is beam spilled out during acceleration. The spike at the right is the beam which spirals into the probe after the rf is turned out. The lower trace are markers of discrete values of magnet current, which provide a measure of the energy of the beam indicated on the upper trace.

position was about 3/4 inch above the geometric median plane. This experiment was done at the injector straight section. A survey was then made of the relative elevation and slope of each sector of the magnet. It was found that the western half of the magnet had settled by an amount up to about 5/8 inch. This is the region adjacent to which the caissons for the shielding foundation had been drilled. The magnet has been realigned to about 1/10 inch by using the foundation jacks provided for that purpose. It remains to be determined by operation whether or not any beam loss was caused by the lack of a flat field.

Magnet Power Supply

On April 7 a generator fault occurred during single-generator operation, which resulted in a small fire at one end of the stator windings. Inspection showed that in addition to the burned area at the end there was a short to the stator laminations near the center of one slot. Repair required the replacement of 10 coils and the removal of fused portions of stator laminations. The bearing alignment of the machine was also corrected when a check showed it to out by about 5 times tolerance. A magniflux inspection of the high-stress regions of the shaft showed no damage. The repairs to the rotation machinery were largely completed by the end of May.

Before the fault it had become increasingly apparent that something might be wrong with the power supply other than the inevitable need for operational adjustments. During the period of magnetic field measurement, November-December 1953, there were 7605 pulses with 31 faults of all kinds, or 245 pulses/fault. During the period of operation February-April 1954 there were 219, 107 pulses on runs when the current never exceeded 1600 amp. There were 67 faults or 3270 pulses/fault. During the same period there were 53, 088 pulses on days when at some time the current exceeded 1600 (but usually not equal to the 8000 amp rating) with 89 faults. The rate was 600 pulses/fault. Not more than 1 fault in 5000 pulses at full load should be expected.

Test operation of the remaining generator after proper monitoring equipment had been installed showed that there were spikes of about 9 kv with a rise time of 1.5 μsec at the generator connections. These rise times are considered excessively short by Westinghouse, and surge capacitors have been installed that increase the rise time to about 10 μsec.

In addition, surges of about a thousand volts have been observed on the grids of the ignitrons. They are known to cause failure of the associated rectox units

and it is believed that they may be due to high ignitron pressure. Several steps have been taken to correct this situation. First, the cooling water system, which has always been heavily loaded with rust, has been purged and a deoxygenator has been installed. Second, the ignitrons have been carefully checked for leaks, which in some cases were repaired here but which in 5 cases were in the anode seal and required factory work. These have not yet been returned. In addition about half the ignitrons have an excessive rate of rise of pressure, even though no leaks have been found. It is believed that they are gassy due to insufficient bakeout, either at the factory or at installation. We are therefore carrying out an extended program of outgassing. The vacuum pumps are being cleaned to bring them up to specified pumping speed.

Extensive checks are also being made of the ignitron control circuits. This work is not yet complete.

The bevatron group consists of Duward Cagle, Warren Chupp, Bruce Cork, Robert Gisser, Walter Hartsough, Harry Heard, Marjorie Hirsh, E. J. Lofgren, Ross Nemetz, Robert Richter, Howard Smith, William Wenzel, Glenn White, and Emery Zajec. The engineering work closely associated with operation has been carried out by groups headed by William Baker, C. A. Harris, D. A. Mack (electrical), and William Salsig (mechanical).

184-INCH CYCLOTRON

Operation Summary

James T. Vale

It was expected that operating time on the cyclotron would be at a premium because of the necessity of completing experiments before the cyclotron was shut down for the conversion. This situation was aggravated by the success encountered with the polarized-beam experimental program. The indications are that after the conversion the degree of polarization of the beam will be so low as to make polarization experiments very difficult, if not impossible. On the other hand, most experiments with mesons should be as easy--if not easier--to do after the conversion for at least two reasons: one, the higher energy will increase the yield; and two, the new meson cave will improve the experimental facilities.

Therefore, it seemed reasonable to give priority to the polarization work for the remaining operating time of the cyclotron. This took effect about the first of April.

Meanwhile the cyclotron has been running very steadily with very little outage, and fortunately no further trouble with the magnet oil leak into the vacuum tank.

60-INCH CYCLOTRON

Operation Summary

William B. Jones

Operations for the 60-inch Cyclotron during this period were as follows:

Alpha bombardments	242.5 hrs
Deuteron bombardments	195.5 hrs
Proton bombardments	136.0 hrs
Carbon bombardments	176.0 hrs
Nitrogen bombardments	51.5 hrs
Experimental bombardments	61.0 hrs
	862.5 hrs
Outage time	177.5 hrs
Overhaul	160.0 hrs
	1200.0 hrs
Shutdown	919.0 hrs
Holiday - Washington's Birthday	16.0 hrs
Daylight Saving Time Change	1.0 hr
	2136.0 hrs

Operations were maintained at approximately 80 percent efficiency prior to the April 16 shutdown for the overhaul. Details of this shutdown and the changes involved will be given in the next Quarterly Report.

LINEAR ACCELERATOR

Operations

James D. Gow

In the period February 1 to April 30, the linear accelerator and Van de Graaff were operated a total of 940 hours for physics research. Some of this time was used in making bombardments with oxygen beam from the Van de Graaff for studies of high-energy ionic stripping. It was found that a usable beam of 0^{++} with 8 Mev of energy could be obtained, as well as some 0^{+++} with 12 Mev.

The 4W20,000 preexciter, which has been under development, was installed on the 40 foot linac in oscillator position No. 1. This position, near the entrance end of the machine, has never been satisfactory for the old radar preexciters. The new preexciter, however, operated very well in this position, giving in excess of 75 kw of rf to the tank. It proved to operate with excellent frequency stability.

The installation of this preexciter has permitted the removal of the lossy element coupling associated with the BC677 preexciters. This change reduced the required main pulse oscillator plate voltage from 17 to 14.5 kv, which should substantially improve tube life in the main oscillators. It has also proved possible to operate at a pulse rate of 30 pulses per second, which doubles the available duty cycle of the machine.

A second gas-supply system for the Van de Graaff ion source has been installed. This system is intended to supply deuterium so that the Van de Graaff can be used for monoenergetic neutron work. It is also possible to accelerate deuterons in the linear accelerator to 16 Mev in the "half velocity" mode. Experiments with deuteron beams will be made.

A policy of operating the Van de Graaff on Saturday day shift, whenever demand warrants, has resulted in the addition of approximately 8 hours per week to the operating schedule. This additional operation is being accomplished without increase in personnel.

SYNCHROTRON

Research

A. Carl Helmholz

The synchrotron operation was fairly good during this three-month period. Owing to the breakdown of the spiral-orbit spectrometer, not all the time was utilized to the best advantage; but at the end of the period the demand for machine time exceeded the supply. There has been regular operation on Saturday for several weeks.

The main part of the running time was taken up by the run for Charles McDonald, Robert W. Kenney, and John Anderson. This run finished up the work on the triplet cross section by the C_6H_6 - C_6H_{12} difference. McDonald is writing this up as his thesis, and the report should be in by June 15. Preliminary estimates indicate that within the experimental error the cross section is equal to that calculated by Borsellino. Some further data were obtained by Kenney in the work on the Compton cross section of Be. Additional data concerned the ratio of pair-production cross sections in Be and Pb. This experiment should be completed now.

Kenneth Bandtel and Dwight Dixon made a preliminary run to test their equipment for measurement of the photodisintegration cross section of the deuteron. It is hoped that they will get a run for this experiment in June. The equipment for

identification of protons operates satisfactorily.

Two short runs for detection of the nuclear resonant scattering of γ-rays by Harry Heckman and Peter Giles were made. Their results so far are in fair agreement with those of other investigators. The possibility that some of the γ-rays may be neutron-capture γ-rays will soon be investigated.

Robert Squire and John Osher used β-rays produced and momentum-analyzed in the pair spectrometer to measure the efficiency of Cerenkov counters. The results were very satisfactory. Some work was done in attempting to get a very short beam, so that, for example, the μ-meson lifetime might be measured with synchrotron-produced π-mesons. Beams of length about 10 μsec are fairly easy to produce, but no beams of the order of 1 μsec have been obtained.

A satisfactory run was made for Sheldon Softky to expose plates for the study of the reaction $C^{12} + \gamma \rightarrow 3\alpha$. In preparation for further running for Walter Dudziak and Ryokichi Sagane with the spiral-orbit spectrometer, a test run was made. In addition some short runs were made for W. Imhof and Victor Perez-Mendez to test the gear for π^+ detection.

Operation

George C. McFarland

The physics research group continued to utilize the synchrotron for furtherance of their program during this report period.

Operation of the accelerator was accomplished with only minor difficulties. Some problems due to warm-weather heating were encountered. This was noticeable in a higher pressure in the vacuum doughnut, and the inability to consistently hold the high voltages in the vacuum chamber. Increased cooling by addition of blowers, and the removal of filters to allow more air flow, has materially helped this problem.

Additional difficulties have been encountered with the rf accelerating system. Apparently the accelerating gap has become partially shorted with carbonized organics. This modification of the gap impedance reduced the efficiency of the accelerating system, and makes it difficult to maintain the required voltages. A replacement resonator is available for installation, but at the present time its replacement is not as important as continuing with some of the physics experiments that are already under way.

Assembly of the Livermore portable electron linear accelerator is approaching completion.

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