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PHYSICS DIVISION QUARTERLY REPORT

May, June, July 1954

September 8, 1954

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Berkeley, California

PHYSICS DIVISION QUARTERLY REPORT

May, June, July 1954

Contents

GENERAL PHYSICS RESEARCH

Polarization in p-n Scattering 4
Polarization of High-Energy Protons in Elastic Scattering on Helium 5
Polarization Experiments Involving Triple Scattering 8

Meson Research with the Spiral-Orbit Spectrometer 12
Bevatron and 184-inch Cyclotron Experiments. 14

Fast Deuterons from High-Energy Nucleons Bombarding Various Elements 17
Gamma-Ray Pair Spectrometer 18
Comparison of the Reactions $p(H^2\pi^+)H^3$ and $p(H^2\pi^o)He^3$ as a Test of Charge Independence 19
Photodisintegration of the Deuteron 20
Cerenkov Radiation Counter and π^o Decay Phenomena 21

Ice-Cube Target 22
Electron-Neutrino Angular Correlation in Ne^{19} 22
Elastic Scattering of Protons 23
Polarization Experiments - Linac Beam at ~3 Mev 23
Polarization Experiments - Linac Beam at ~9.5 Mev 23
Polarization Experiments - Cyclotron Polarized Beam at ~10 Mev. 24
Polarization Experiment - Cyclotron Polarized Beam at 135 Mev and 270 Mev 24
Scattering of Polarized Protons in Hydrogen 25
Polarization Experiment - Cyclotron Polarized Beam at ~30 Mev . . 25
Experiments on Polarization at 32 Mev 26
Two-Crystal Neutron Spectrometer 26
$p + p \rightarrow \pi^+ + d$ Cross Section near Threshold 27
$p + p \rightarrow \pi^+ + d$ with Polarized Protons 30
Liquid-Hydrogen Glaser Bubble Chamber 31
Gamma-Ray Scattering from Hydrogen 32

Film Program 33

Cloud Chamber Studies 35

*Previous Quarterly Reports: UCRL-2630, 2513

Theoretical Group 36

ACCELERATOR OPERATION AND DEVELOPMENT

Bevatron 40

184-Inch Cyclotron 46

60-Inch Cyclotron 48

Linear Accelerator 49

Synchrotron 51

PHYSICS DIVISION QUARTERLY REPORT

May, June, July 1954

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

GENERAL PHYSICS RESEARCH

POLARIZATION IN p-n SCATTERING

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

A liquid-deuterium target has been placed in the polarized proton beam (312 Mev, 74-percent polarized), and the scattering processes observed in several ways. The main objective was the observation of the p-n scattering, in which the deuterium nucleus was to be considered as containing a very loosely bound neutron. For some angles of p-n scattering, the scattered neutrons were counted singly in a counter specifically designed to count neutrons of high energy only. At other angles, scattered neutrons and scattered protons were counted in coincidence.

In the course of these experiments pairs of scattered protons were also counted in coincidence. These events were p-p scattering processes. The polarization results obtained were in agreement with those from hydrogen scattering, indicating that the deuteron binding had no appreciable effect on the polarization observed.

The neutron counter employed consisted of alternate plastic scintillation counters 3 x 3 x 1/4 in. and pieces of polyethylene 3 x 3 x 1.5 in., surrounded by some shielding and some anticoincidence counters to reject charged particles coming from the outside. Neutrons were counted when they caused proton recoils in the material of the counters or in the polyethylene. When neutrons were to be counted singly, the electronic circuits were arranged to count only those events in which three counters in a row (or, in some cases, two counters in a row) counted in coincidence. This served to reject neutrons of very low energy.

The results of this work have been reported in the Physical Review* and in UCRL-2611. The results are summarized in Fig. 1, which shows the product $P\sigma$ for p-n scattering plotted as a function of the center-of-mass scattering angle θ.

POLARIZATION OF HIGH-ENERGY PROTONS IN ELASTIC SCATTERING ON HELIUM

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

A liquid-helium target has been placed in the high-energy polarized proton beam of the 184-inch cyclotron. At the time of this run the beam energy was 319 Mev and the beam polarization was 74 percent. The cross sections for elastic scattering to the left and right sides of the beam were measured. Because the beam polarization was known the scattering data could be used to compute $P(\Theta)$, the polarization induced in an unpolarized beam by elastic scattering on helium at angle Θ. These helium data are shown in Fig. 2.

Helium is unique among the complex nuclei studied thus far in that the sign of the polarization is not the same for all angles. The usual sign is found for small angles, but at about 26° the polarization is zero and at larger angles the polarization has the opposite sign.

The helium data are of special interest because the experiment itself can be better performed for helium than for other substances. The method of eliminating all except elastic scattering consists in placing sufficient absorber in the counter telescope to reject all but the highest-energy component of scattered protons. Because of range straggling and beam inhomogeneity, the counter telescope still accepts any protons that are within about 20 Mev of the maximum energy. Since helium has no excited or unbound states at less than 20 Mev, inelastic scattering events may be completely rejected.

The same cannot be said of scattering from other complex nuclei, such as carbon. Inelastic scattering may occur in which the nucleus is excited by less than 20 Mev, and at least some of the resulting protons will be

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*Chamberlain, Donaldson, Segrè, Tripp, Wiegand, and Ypsilantis, Phys. Rev. 95, 850 (1954)

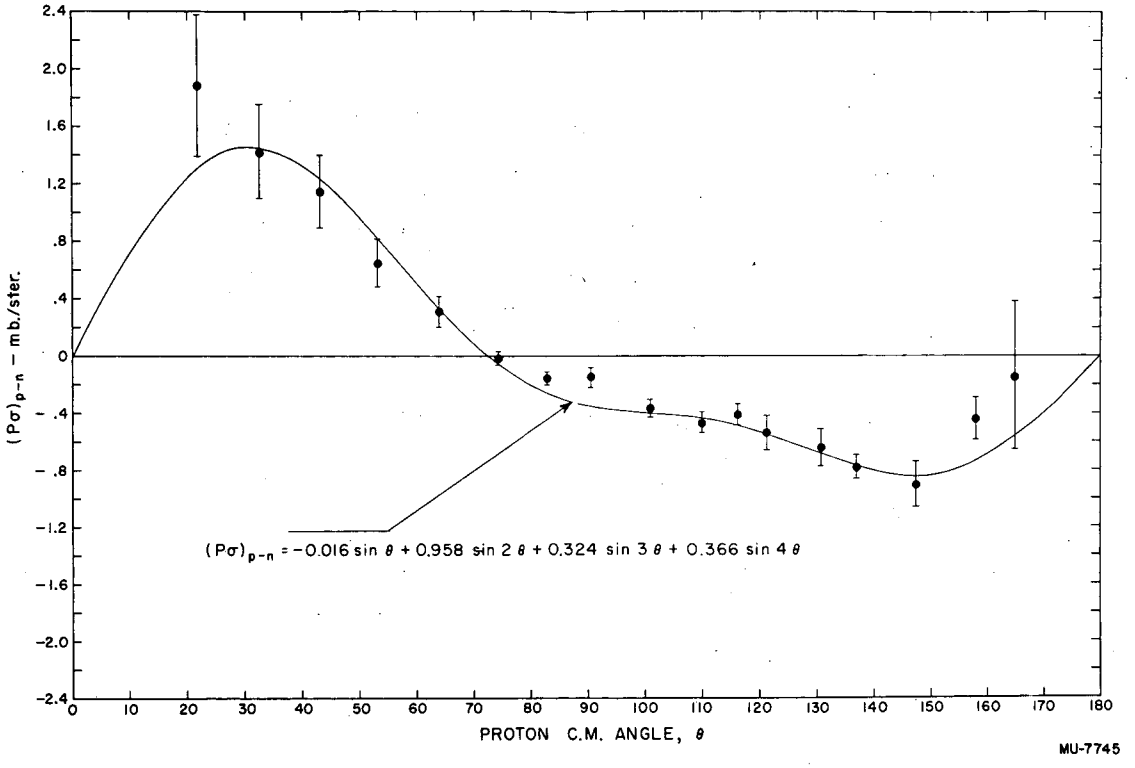

2.4
2.0
1.6
1.2
.8
.4
0
-.4
-.8
-1.2
-1.6
-2.0
-2.4
$(P\sigma)_{p-n}$ – mb./ster.
$(P\sigma)_{p-n} = -0.016 \sin\theta + 0.958 \sin 2\theta + 0.324 \sin 3\theta + 0.366 \sin 4\theta$
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
PROTON C.M. ANGLE, θ
MU-7745

Fig. 1

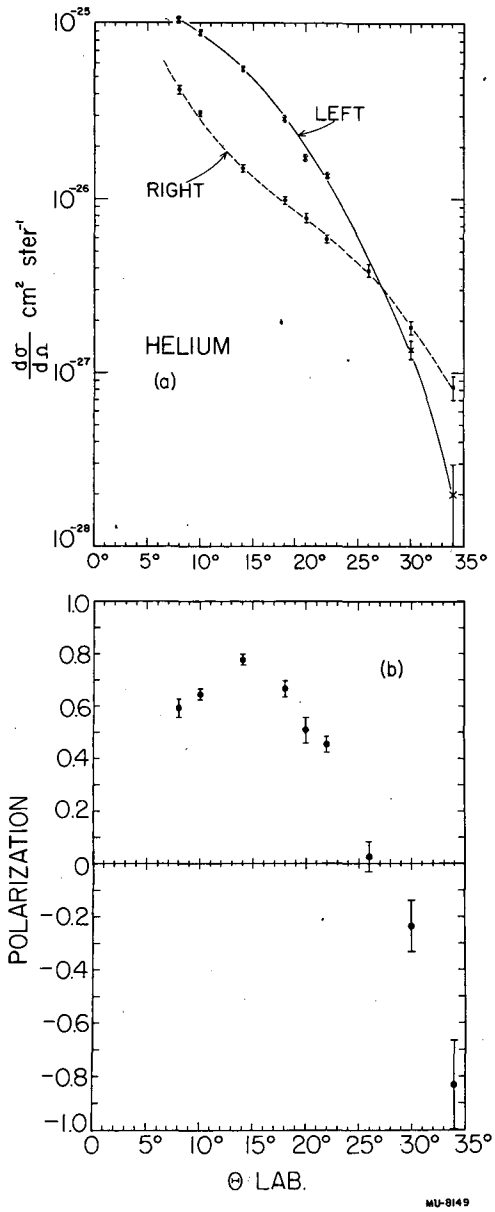

LEFT
RIGHT
HELIUM
(a)
$\frac{d\sigma}{d\Omega}$ cm^2 ster^{-1}
10^{-25}
10^{-26}
10^{-27}
10^{-28}
0° 5° 10° 15° 20° 25° 30° 35°
(b)
POLARIZATION
1.0
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1.0
0 5° 10° 15° 20° 25° 30° 35°
Θ LAB.
MU-8149

Fig. 2

counted in our apparatus as elastically scattered.

The purely elastic scattering from any element can still be measured at small angles to the beam, because the elastic scattering is large enough to mask the inelastic scattering completely. In the case of carbon, our existing data are safely restricted to elastic scattering for angles less than 20°.

Comparison of helium and carbon data for angles less than 20° shows that these two elements have nearly the same polarization in this region. This bears out a prediction* made by Dr. Tamor of this laboratory that among the light elements all the alpha-particle nuclei should have the same polarization. Tamor's prediction was based on the impulse approximation.

POLARIZATION EXPERIMENTS INVOLVING TRIPLE SCATTERING

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

The polarized (once-scattered) beam has been obtained in the cave with an intensity of 10^6 protons per second through a 2-in.-diameter collimator. The beam energy is about 312 Mev, and the polarization is 74 percent. This intensity is sufficient to allow two more successive scatterings, as suggested to us by Dr. Lincoln Wolfenstein. In a typical arrangement the second target is $1 g/cm^2$ of liquid hydrogen and the third target (placed about 40 inches from the second target) is $6 g/cm^2$ of carbon. The area of the third target is 9 $in.^2$ Under these circumstances there are about 30 protons per second (twice-scattered) impinging on the third target, of which about 0.04 per second are scattered by the last target into a counter telescope. This corresponds to an actual counting efficiency of 1/800 of the protons reaching the last target. By comparing left and right scattering at the third target we can determine one component of the polarization (spin orientation) of the beam after it has been scattered by the material of the second target.

In visualizing the meaning of the triple-scattering experiments it is helpful to refer to the analogy with optical phenomena. The scattering at the first target (in the internal cyclotron beam) serves to polarize the beam in a known fashion and may be compared to the action of a Nicol prism on light. In all the triple-scattering experiments the conditions at the first target are adjusted

*S. Tamor, Phys. Rev. 94, 1087 (1954).

to give the maximum polarization consistent with good beam intensity. In a similar way the scattering at the third target serves to analyze the polarization of the particles reaching there, and may be compared to another Nicol prism acting to analyze a light beam. The conditions at the third target are always adjusted to give the best analyzer consistent with good detection efficiency. The scattering at the second target corresponds to properties of the medium under study in an optical system. The material of the second target may be varied, and the angle of scattering at the second target may be varied, for it is really the scattering at the second target that is under study.

Some work has been done on the triple scattering using a carbon second target. The essential details of the counting arrangement used are shown in Fig. 3. All the vectors shown in the figure are in the plane of the figure. The incident polarized protons are shown with their direction of polarization P_B, which is normal to their direction of motion. The protons of interest are those that are scattered by an angle Θ_2 at target B (of carbon) and reach Target C. The analysis of the polarization of these protons depends on determining their asymmetry of scattering at the third target. The last counters are not in the plane of the figure, so are not shown there, but the normal to the last scattering plane is shown as $\underline{n}_3$ in the figure. The component of the polarization that is readily measurable is the component in the direction of $\underline{n}_3$. By determining the extent of polarization in the direction of $\underline{n}_3$, we can estimate the extent to which the original polarization has been rotated in the scattering at the second target (B).

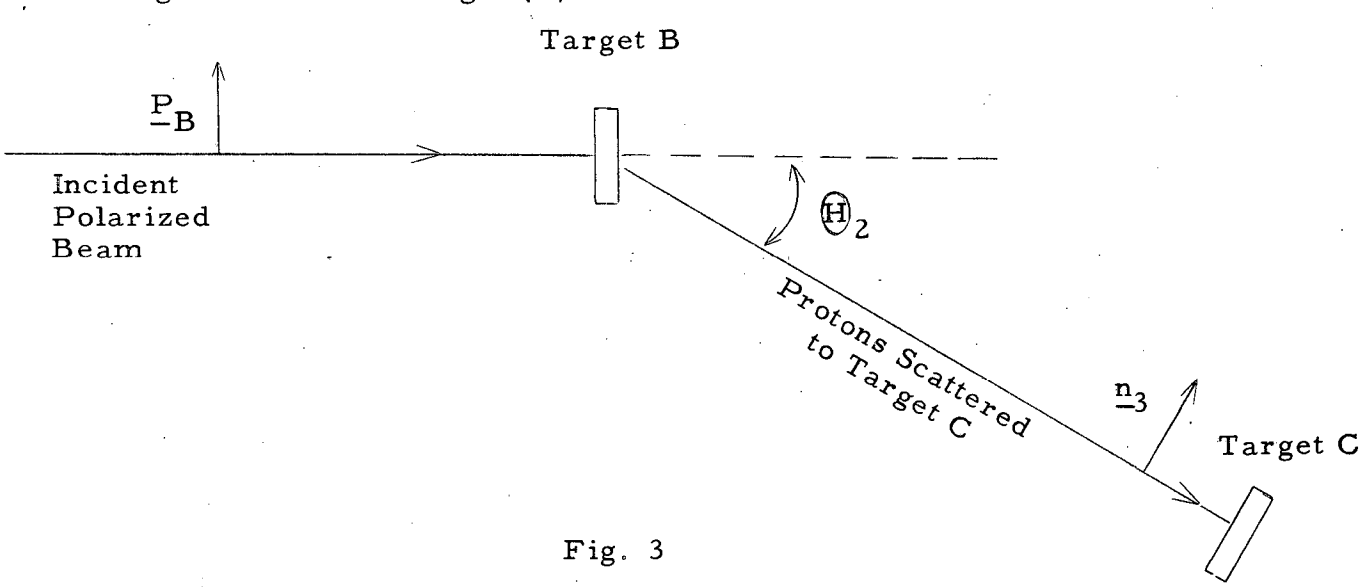


Fig. 3

Theoretical analysis of the carbon triple scattering shows that if the scattering at the second target is elastic, then the only effect not already determined in double-scattering experiments is the extent of rotation of the polarization in the plane of the figure. In performing the experiment, sufficient absorber is placed in the counter telescope to effectively restrict the counted protons to those that are elastically scattered at all the targets.

In order to obtain complete information about the meaning of the asymmetry at the third scattering, it is necessary to determine the analyzing power of the arrangement at the third target. This is accomplished by eliminating the second target (target B) and placing the third target assembly in the known polarized beam and determining the asymmetry. When this is done, some absorber is placed in the beam ahead of the third target so that the energy of the particles reaching the last target is the same as for the actual triple-scattering arrangement. The analyzing power of the third-scattering arrangement is between 0.45 and 0.7, depending on the energy of protons reaching the third target.

For elastic scattering from a spin-zero nucleus, the scattering amplitude can be written as

$$f(\theta) = g(\theta) + h(\theta)\,\underline{\sigma}\cdot\underline{n},$$

where $\sigma \cdot n$ is twice the component of the proton spin in the direction of the normal to the scattering plane. The fact that the polarization in scattering by carbon is quite large indicates that g and h are at least roughly comparable to each other in magnitude, and the existing theories of the polarization process indicate that g should be larger than h. The triple-scattering experiments confirm this expectation by indicating (for $\Theta_2 = 11^\circ$ and 14°) that the angle by which the polarization has been rotated at the second target as about 60°. If h had been larger than g, then the angle of rotation of the polarization would have been larger than 90°.

Some triple-scattering experiments have also been done with a hydrogen second target. For hydrogen there are two types of triple-scattering experiment to be performed. One is the same as that described for a carbon second target, and serves to determine the extent to which the polarization direction has been rotated in the second scattering. In the other type of triple-scatter-

ing experiment all three scattering planes are parallel, and the experiment is aimed at determining how much depolarization occurs during the scattering from hydrogen.

The experiments using hydrogen are still in progress, and their interpretation is still under study. It is hoped that the depolarization and rotation factors can be related to the phase shifts for p-p scattering. When combined with the data on differential cross section and polarization (from double-scattering experiments) they may allow a considerable amount of information about the phase shifts to be obtained. It must be emphasized, however, that the counting rates of the triple-scattering experiments are always very low, so that only a very limited statistical accuracy can be achieved.

MESON RESEARCH WITH THE SPIRAL-ORBIT SPECTROMETER

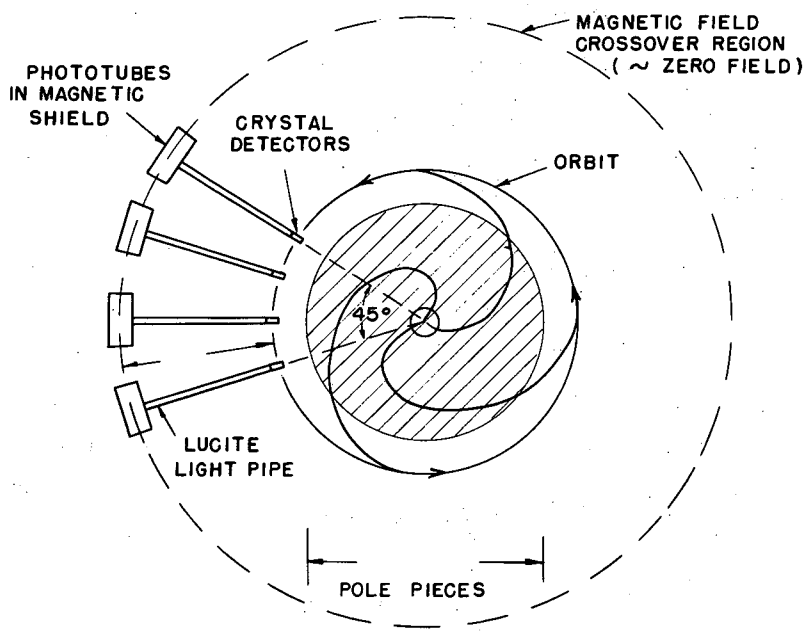
Ryokichi Sagane and Walter F. Dudziak

Because of the proposed plans for conversion of the 184-inch cyclotron, no cyclotron time was set aside for meson research with the spectrometer. The 40-inch spectrometer was moved to the synchrotron. The concrete floor in Bldg. 25 could not support the concentrated load of the spectrometer near the synchrotron. It yielded over one inch in one hour. The spectrometer was therefore placed at the far end of the synchrotron, where the concrete floor is two feet thick. The disadvantage of the loss in beam intensity upon moving away from the synchrotron was compensated by the fact that sufficient space was available for another experimental setup in front of the spectrometer. Therefore it usually was possible for two groups to run an experiment during the time that the spectrometer was in use. Furthermore it was found that because of the presence of the spectrometer magnetic field, higher γ-ray beam levels are possible.

A large portion of the running time was devoted to successful development of a coincidence measuring technique for the detection of π^+ and π^- mesons. Figure 4 is a schematic diagram of the detection method used for quadruple coincidence. Because of the spiral-orbit principle, pions of a given energy, created at the target by the photon beam, are brought to a focus at the stable orbit. Therefore only a range measurement is required to definitely establish the type of charged particle producing the coincidence. For both π^- and π^+, a plot of the rate of quadruple coincidence against range produced a sharp drop-off at a somewhat lower value of the range than the corresponding Aron range calculated for that particular pion energy.

Because of the long counting periods necessary at the synchrotron a small drift in detection efficiency was found. To minimize this effect proper shielding was introduced between the crystals, and the π^+ and π^- mesons were detected at the same time, using double coincidence. For the negative pion a sharp range-counting-rate curve was obtained similar to that for quadruple coincidence. However, no sharp range curve could be obtained for the positive pions; the positron emission from the stopped pions in the lead shield separating the two sets of crystals obscured this effect. Two additional crystals, therefore, were introduced into the stable orbit (one on each side of the lead shield). This permitted the detection of both charged pions at the

SPIRAL ORBIT SPECTROMETER
MEDIAN PLANE OF GAP



MU 1809

Fig. 4

same time, using triple coincidence. A typical range-counting-rate curve is shown in Fig. 5.

With the methods described the following preliminary determinations were made:

(a) A part of the $\pi^{\pm}$ production spectrum from carbon as a function of energy, using double, triple, and quadruple coincidence.

(b) A part of the production spectrum for $\pi^{\pm}$ mesons from deuterium, using the modified high-pressure hydrogen target. For this case quadruple coincidence was used; only one sign of the charged pion was measured at a time.

(c) An initial test on the variation of the production cross section for both π^{+} and π^{-} mesons as a function of atomic number in the low pion-energy region.

(d) A study of the $\gamma + p \rightarrow \pi^{+}$ production problem in the low pion-energy region by means of a $C - CH_2$ subtraction technique.

BEVATRON AND 184-INCH CYCLOTRON EXPERIMENTS

Robert Birge, Roy Haddock, Leroy Kerth, Jack Merritt, Chaim Richman

Bevatron

A. Designs were completed and work was started on a second reentrant well to be installed in the west wall of the west tangent tank of the bevatron to allow half-life measurements of heavy mesons to be at 90° to the beam. The vertical plunging probe that will be used in conjunction with this well has been completed and the scintillator associated with it has been tested.

Two scintillation counter telescopes have been tested with a 3-Bev beam of about 10^5 protons per pulse. At a distance of about one foot from a plunging target these telescopes give a few counts per pulse when gated. Ungated rates are about five times as fast. The total time the machine has operated at these levels has only amounted to a few hours, and therefore no exact measurements have been made.

B. A complete set of experiments has been run to determine the grain count in emulsions under all possible combinations of time and temperature of

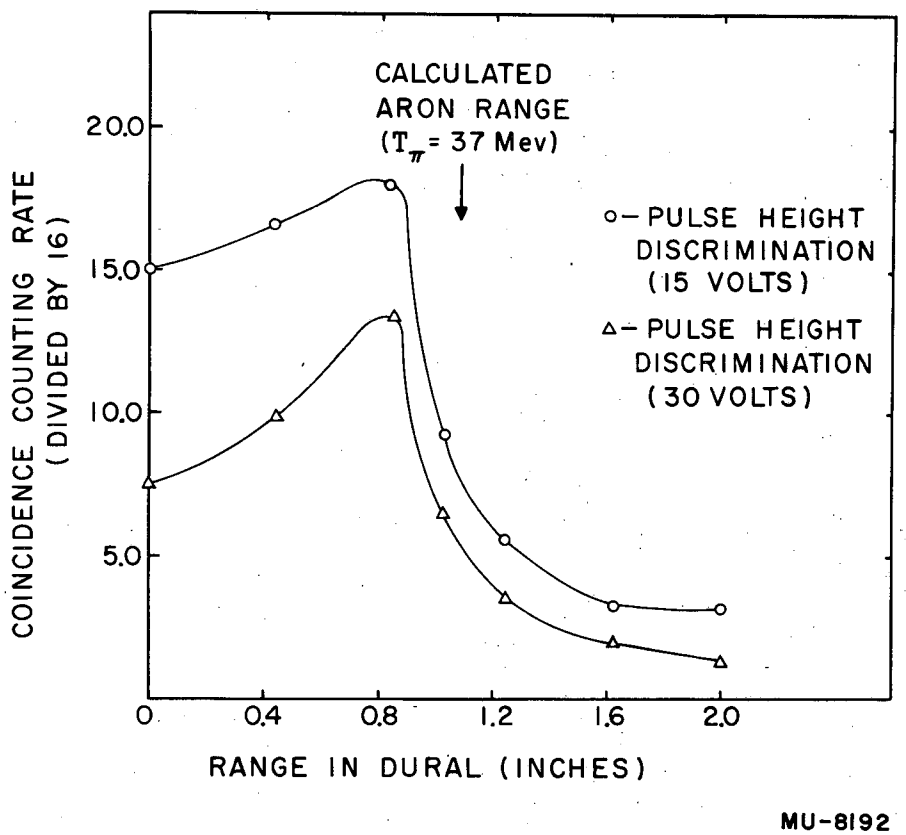

CALCULATED
ARON RANGE
(T_π = 37 Mev)
o– PULSE HEIGHT DISCRIMINATION (15 VOLTS)
Δ– PULSE HEIGHT DISCRIMINATION (30 VOLTS)
COINCIDENCE COUNTING RATE (DIVIDED BY 16)
20.0
15.0
10.0
5.0
0
0.4
0.8
1.2
1.6
2.0
RANGE IN DURAL (INCHES)
MU-8192

Fig. 5

development. A separate report will be written giving details of these and other emulsion tests.

C. A square matrix to be used for relocating events in nuclear emulsions has been made. It was set up in type and photographically reduced from 36 inches square to 6 inches square, and consists of 150 x 150 squares with two 3-digit numbers in each square.

The matrix is photographed onto glass plates and the emulsion pellicles are then mounted on these plates rather than on the treated glass normally used.

184-inch Cyclotron Experiments

Preparations are being made to study the angular distribution of 20-Mev positive pions scattered into an emulsion stack from liquid hydrogen.

The double-focusing properties of the wedge-shaped pair spectrometer magnet have been studied and will be used to obtain a sufficient pion beam intensity with small energy dispersion. Two quadrupole focusing-magnet sections have been built to focus the external 340-Mev scattered proton beam from the 184-inch cyclotron.

The pion beam will pass through a collimator in the concrete "cave" wall, permitting the emulsion stack to be placed in a region known from previous studies to be sufficiently free of background.

FAST DEUTERONS FROM HIGH-ENERGY NUCLEONS BOMBARDING VARIOUS ELEMENTS

Wilmot N. Hess

The data obtained in a run made at 40° to the 300-Mev neutron beam have been analyzed, and the values for the fraction f of surface nucleons that are neutrons have been determined. These are listed below:

Li	$f = 0.564 \pm 0.115$
C	$f = 0.470 \pm 0.077$
Cu	$f = 0.699 \pm 0.075$
Cd	$f = 0.612 \pm 0.064$
Pb	$f = 0.775 \pm 0.090$
U	$f = 0.745 \pm 0.078$

For Li and C the values of f are the same as the comparable volume fraction, which is N/A. For heavier elements, and especially for Pb and U, the value of f is significantly higher than N/A. This shows that for heavy elements there is a nuclear skin that is predominantly neutrons. This has been anticipated theoretically* and is a result of the Coulomb potential.

An attempt has been made to fit the observed deuteron yields and spectra by using the indirect pickup model of Bransden**, which yields the following relation between the deuteron spectrum and the spectra of scattered neutrons and protons:

$$\frac{d\sigma}{d\Omega dE}\, p+x \rightarrow d = \left[\frac{d\sigma}{d\Omega dE}\, p+x \rightarrow p\right] P_1 + \left[\frac{d\sigma}{d\Omega dE}\, p+x \rightarrow n\right] P_2$$

where P_1 = Probability that a proton pick up a neutron

P_2 = Probability that a neutron pick up a proton

for a carbon target $P_1 = P_2$.

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*Johnson and Teller, Phys. Rev. 93, 357 (1954).

**Bransden, Proc. Phys. Soc. A 65, 738 (1952).

In this experiment we have measured $\frac{d\sigma}{d\Omega dE}\, p+x \rightarrow p$

and we can make a reasonable guess at $\frac{d\sigma}{d\Omega dE}\, p+x \rightarrow n$

by taking $\frac{d\sigma}{d\Omega dE}\, p+x \rightarrow p$

and weighting it by the ratio of free-nucleon cross sections given by

$$\frac{\sigma\, np\, (\theta)}{\sigma\, pp\, (\theta)}$$

Using these energy spectra and choosing a power law for the energy dependence of the pickup process $P = kE^{-n}$, we can try to fit the observed deuteron energy spectra and also the areas under the spectra that are the differential cross sections. The best fit is given by $P = 0.12E^{-2.5}$. The data can be fit quite well by any value of n from 2 to 4.

GAMMA-RAY PAIR SPECTROMETER

Harlan Shaw and Charles Waddell

The improvements in high-energy pair spectrometer techniques, which have been developed during the recent research on proton bremsstrahlung and on the 15.2-Mev gamma emission from C^{12}, have made it possible to secure more precise data on the total emission spectrum from π's produced in the cyclotron target. In an effort to reinvestigate the symmetry of this spectrum with a spectrometer that gives good data on the low-energy side of its maximum, runs were made during May and June in which the gamma energy spectrum from π^0 production by 340-Mev protons on carbon was obtained. Data were taken at 0°, 47°, 90°, 133°, and 180° in the laboratory system.

The spectrum at 90° was viewed by a 180° pair spectrometer down a hollow probe placed along the main probe radius. The data at 0°, 47°, 133°, and 180° were taken by moving the spectrometer to the neutron hole, where it viewed the same target arrangement at the same cyclotron radius. Monitoring of the internal beam was done by our thermocouple system, which measures

the power dissipated in the target. This provided an accurate measure of the relative cross sections at the five angles.

Coincidentally with measuring the π^o angular distribution, we saw the previously reported 15-Mev gamma line from carbon, thus measuring its angular distribution from 340-Mev protons.

Also during June the proton bremsstrahlung spectra from 180-Mev proton bombardment of Be, Al, and Cu at 0° and 180° (lab system) were measured.

Work on the 15-Mev gamma line from proton bombardment of carbon was reported at the Seattle meeting of the American Physical Society. It has been decided that the threshold for producing the line by proton bombardment must be determined in order to find out whether the line arises from a 15-Mev excited level in carbon, or from a higher excited level around 20 Mev, or possibly from an excited level in Be. In this connection, one of the beam-focusing magnets is being modified to take the present pair-spectrometer vacuum chamber. The present pair magnet weighs 17 tons and cannot be moved conveniently from Bldg. 6 to the other accelerators. The new spectrometer will be portable, and will make use of a number of improvements in design to enhance the resolution and lower the minimum gamma energy that can be measured. In order to increase the counting rate, particularly at accelerators such as the bevatron and synchrotron which have slow repetition rates, a system to replace the present Geiger tubes with plastic scintillators and high-speed electronics is under consideration.

COMPARISON OF THE REACTIONS $p(H^2\pi^+)H^3$ AND $p(H^2\pi^o)He^3$ AS A TEST OF CHARGE INDEPENDENCE

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

The ratio of the two reactions has been determined at one angle to be 2.3±0.3. Owing to the delay in cyclotron shutdown, there will now be time available for the measurement of the angular distribution and yield of the reaction $p(H^2\pi^o)He^3$ to compare with the already measured angular distribution of the reaction $p(H^2\pi^+)H^3$.

Preliminary work is being done. It is planned to measure and identify the unique-energy He^3 particle at each angle by pulse-height techniques. Background will be eliminated by time of flight, using a fast gate derived from the beam envelope (the rf fine structure). Work is under way on this device. More details will follow in later reports.

PHOTODISINTEGRATION OF THE DEUTERON

Dwight R. Dixon and Kenneth C. Bandtel

Differential cross sections for photodisintegration of the deuteron by high-energy gamma rays have been measured at laboratory angles of 49°, 75°, 106°, and 141°. Measurements were made at nine gamma-ray energies ranging from 136 to 292 Mev in the laboratory system. The liquid-deuterium target and the $\frac{dE}{dx}$ – Range counter, which was described previously, were used in the experiment. Cross sections were determined to about ±10%, excepting at 141°, where the statistics were somewhat poorer. No corrections have yet been made for nuclear scattering. A previous experiment indicated that this correction will increase the cross section by about 20% in some cases.

The angular distribution is peaked forward, dropping from about 6 mb/steradian at 49° to about 2 mb/steradian at 141° for the intermediate energies. No great variation of cross section with energy is evident. The cross sections when corrected for nuclear absorption will probably show a gradual increase with energy. At 75° and 141° the 292-Mev points are somewhat lower than the 264-Mev points. These results are in general agreement with those from Cornell (Keck et al., Phys. Rev. 93, 827), from Illinois (Dwight-Schiever et al., Bull. Am. Phys. Soc. 29, No. 1), and from California Institute of Technology (Keck et al., Bull. Am. Phys. Soc. 29, No. 6).

During the experiment the beam was monitored by a thick-wall Cornell-type ion chamber and by the precollimator ion chamber. The latter was calibrated during the run using the Blocker-Kenney method. The calibration data on the former chamber were obtained at Cornell using a pair spectrometer. The integrated beam as measured by the two monitors differed by about 11%.

An attempt was made to measure cross sections at 24° with respect to the photon beam. With the experimental arrangement used it proved impossible to make a clean separation of the protons from the background. It may be possible to obtain useful data at this angle by using a thicker deuterium container with thinner walls and by taking other steps to reduce the background.

CERENKOV RADIATION COUNTER AND π^{o} DECAY PHENOMENA

Robert K. Squire and John E. Osher

The Cerenkov counter previously reported was used on a preliminary run for measuring the angular distribution of $p + p \rightarrow p + p + \pi^{o}$. The initial run disclosed a number of important considerations in this experiment, among them that a combination of crystal γ telescope and Cerenkov counter was needed to detect a low yield of high-energy gammas in a large background of charged particles and neutrons. Also, it was found that great care was necessary in target design in order to eliminate target-wall effects with a reasonable amount of collimation for the telescope; the final design uses a large liquid-hydrogen target constructed of two 1-inch styrofoam walls with a 1/2-mil Ni inner liner.

A major run with appropriately revised equipment is scheduled for the first week in August to resolve the angular distribution and excitation function for the process given above; additional runs may be necessary, however, because of the very slow counting rate.

ICE-CUBE TARGET

Richard L. Blumberg

A machine is under construction to make hydrogen "ice cubes" that could be dropped at the peak of each bevatron beam pulse. Preliminary operation with nitrogen was successful and several pills were made, though nowhere near 6/minute.

A column of liquid (nitrogen at present) 1/8 in. in diameter is cooled to solid by vacuum-pumping liquid in a surrounding vessel. The solid column is then shoved down into a valve leaf. The leaf is moved, first shearing the pill off the column to length (3/16 in.), then sealing off the column, and finally permitting the pill to drop into a vacuum chamber.

The nitrogen pills dropped onto an iron plate retained their cylindrical shape and lasted 2 to 3 minutes before subliming away.

The valve is made from spring-loaded, hardened-steel, optically flat plates. Its leak rate at low temperatures has not been determined, but it is helium-leak-detector-tight at room temperatures. An optical dip stick has proved useful for liquid-level measurement. Temperature control is done with a vapor pressure thermometer.

The machine is in the shop at present for minor modifications and addition of hydrogen safety devices, after which a run with hydrogen will be attempted.

ELECTRON-NEUTRINO ANGULAR CORRELATION IN Ne^{19}

Myron L. Good and Eugene J. Lauer

Several linear accelerator runs using the differential pumping apparatus have been completed. After some initial difficulty with extraneous activities was eliminated, a significant counting rate for electron-recoil coincidences was observed. Some preliminary film data on the time distribution of the recoils were taken and are now being analyzed.

ELASTIC SCATTERING OF PROTONS

John Leahy

Angular distribution of elastically scattered 31.5-Mev protons on gold is now under way. The cross section has been measured at several angles between 10° and 75° in the laboratory system, showing a definite minimum around 35° and indicating another between 60° and 75°.

POLARIZATION EXPERIMENTS USING LINEAR ACCELERATOR BEAM REDUCED IN ENERGY TO APPROXIMATELY 3 MEV

Hugh Bradner and Edwin Iloff

An attempt is being made to determine the sign of 32-Mev polarization by absorbing a once-scattered beam to an energy where its second scattering in helium will be strongly polarized*. Two runs have been made. A minimum of eight hours' bombardment is required to obtain sufficient yield of doubly scattered particles. The accumulated background in the plates due to neutrons and gamma rays is very large.

Recent communication with Dodder indicates that the polarization of 9.5-Mev protons scattered on hydrogen should still be large. We have just completed one run at this energy. Plates are not yet examined.

POLARIZATION EXPERIMENT USING LINEAR ACCELERATOR BEAM REDUCED IN ENERGY TO 9.5 MEV

Hugh Bradner and Edwin Iloff

Two runs have been made with protons of approximately 10 Mev scattered in a pressurized helium target. The background is large. No further work is contemplated on this helium scattering until a more highly polarized

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*Myron Heusinkveld, Thesis, University of Minnesota (1951).

initial beam is available or until John Williams, at the University of Minnesota, obtains information on the polarization from an initial 10-Mev proton beam scattered in helium.

Further communication with Dodder indicates that the phase shifts used for the extrapolation of the 3.5-to-4-Mev polarization up to 9.5 Mev are not unambiguous. Williams's experiments should clarify this point for us.

POLARIZATION EXPERIMENTS USING THE CYCLOTRON POLARIZED BEAM REDUCED IN ENERGY TO APPROXIMATELY 10 MEV

Hugh Bradner and Edwin Iloff

Two runs were made with the high-pressure helium chamber filled to 750 psi. The background on the plates appears satisfactory, except that the real scattering events can be confused with short tracks due to radioactive decays in the emulsion. A batch of plates are being eradicated, and a shipment of emulsion for pouring fresh plates is being ordered from Ilford so that this difficulty can be avoided in future runs.

Analysis favors the same polarization as the 300 - 135 - 70 - 32-Mev carbon data, viz. an attractive spin-orbit coupling.

POLARIZATION EXPERIMENT USING CYCLOTRON POLARIZED BEAM REDUCED IN ENERGY TO 135 MEV AND 270 MEV

Hugh Bradner, Edwin Iloff, Robert D. Tripp, Thomas J. Ypsilantis

One run was made with the assistance of Ypsilantis and Tripp. The polarization of the beam was observed after scattering at the two above-named energies on a carbon target at angles of 10°, 15°, and 20°. The magnitude of the polarization at 135 Mev is approximately the same as Ypsilantis has found at 300 Mev. The size of the polarization takes an abrupt drop between 135 Mev and 70 Mev, but still maintains the same sign for all the points investigated.

SCATTERING OF POLARIZED PROTONS IN HYDROGEN

Hugh Bradner and Edwin Iloff

The 73%-polarized proton beam of the cyclotron was absorbed to 30 Mev, and then passed through water-loaded G5 emulsions. These plates are being scanned for possible asymmetry of the characteristic hydrogen scatters in the emulsion. Exposures were made independently by Goldhaber and by Bradner. The plates are being scanned jointly by the two groups.

POLARIZATION EXPERIMENT USING THE CYCLOTRON POLARIZED BEAM ABSORBED TO APPROXIMATELY 30 MEV

Hugh Bradner and Edwin Iloff

One run has been made in the program to determine the sign of polarization. The 73%-polarized beam was absorbed to a nominal energy of approximately 30 Mev. This reduced-energy beam was then scattered approximately 45° in carbon and detected in nuclear plates. The plates have been partially scanned. The observed asymmetry is approximately 6% and is of the same sign as is found at 300 Mev and 30° scattering from carbon. The low magnitude of the asymmetry observed cannot be considered to imply that the polarization at 30 Mev is indeed small, because the straggling of the cyclotron beam when reduced to this energy is very large and hence there is no way of separating elastic from inelastic events.

The fact that the sign of the asymmetry does not reverse in going from 300 Mev to 135, 70, and 30 Mev may be of significance in determining the sign of the spin-orbit coupling. Warren Heckrotte has pointed out that his preliminary calculations indicate a change in the sign of asymmetry between 30 and 300 Mev for one assumed spin-orbit sign and not for the other.

EXPERIMENTS ON POLARIZATION AT 32 MEV

Hugh Bradner and Edwin Iloff

Scattering angles have been extended to 40° and 82° by means of new plate holders. Scanning of plates obtained with protons double-scattered at 40° on carbon has been partially completed. The small number of tracks thus far observed indicates an asymmetry of 10% ± 5%. Carbon was used here in order to make observations near the first minimum of the diffraction scattering. Elements with higher Z have Rutherford scattering that is too large; elements with lower Z have their diffraction minimum at larger angles, and hence the yields are very small. The 82° scattering angle was accomplished at the expense of angular resolution, which, however, is feasible by the particular choice of 82°. This is approximately the angle of the second maximum of the diffraction pattern; hence in the vicinity of this angle the cross section is changing slowly and the use of a target holder with $\pm 5^{\circ}$ resolution does not introduce excessively spurious asymmetries. These plates are in the process of being scanned.

TWO-CRYSTAL NEUTRON SPECTROMETER

George Hecht and Robert Silver

Most of the instrumental difficulties in the two-crystal neutron spectrometer have been worked out. The method of using a proportional counter between the two crystals to differentiate between recoil protons and Compton electrons and thus to distinguish between neutron events and gamma events respectively has proven successful. Thus the instrument can be used either as a neutron spectrometer or a gamma spectrometer, although the plans at present are for analyzing only neutron events.

A spectrum at 32° of neutrons from beryllium excited by bombardment by 31-Mev protons from the linac shows a relatively flat distribution from 5 Mev to 30 Mev with about 10% energy resolution. Useful counting rates are of the order of 4 per minute. Background is the limiting factor despite

the use of fast (10^{-8} second) electronics in the crystal circuits. More investigation into the background problem is planned.

The possible use of a thin plastic scintillator to replace the proportional counter has been considered, and a 1-mil plastic crystal was prepared and briefly tested. Although this thin crystal does count, it is not yet known whether it will be useful to distinguish particles by $\frac{dE}{dx}$.

On the basis of the experience obtained so far, new counters were designed to minimize all known experimental difficulties. The new counter setup was tested in a run and an improvement of the order of 6 in neutron counting rate per unit of proton beam charge was observed. The spectra from this run have not yet been plotted.

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

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

More measurements were performed in May, at c.m. angles from 55° to 80°, and at cyclotron energies of 339 and 310 Mev. In addition, the twelve absolute differential cross sections that comprise all the data to date were fit by least squares to the phenomenological theory of Brueckner and Watson, which predicts

$$4\pi \frac{d\sigma}{d\Omega} = \alpha_{10}\, \eta + \beta_{10}\, \eta^3 \; \frac{(x + \cos^2\theta)}{x + 1/3} \qquad (1)$$

Here $\eta = p\pi\,(\text{c.m.})/m\pi c$; $\alpha_{10}\,\eta$ and $\beta_{10}\,\eta^3$ are the S-wave and P-wave contributions, respectively, to the total cross section; and x gives the P-wave angular distribution. In order to perform a least-squares analysis easily, one needs an expression linear in the parameters, so we rewrite

$$4\pi \frac{d\sigma}{d\Omega} = a_1\, \eta + a_2\, \eta^3 + a_3\, \eta^3 \cos^2\theta. \qquad (2)$$

In all our previous publications we had believed that it was necessary to incorporate the relative excitation data at 0° of Schulz, in order to find the

energy dependence of the angular distribution. However, if one inspects the above formula he sees that a_1 and a_2 can be determined by two different energy points at 90° (c.m.), after which a_3 can be determined by one good angular distribution at a single energy. Of course, more measurements are needed in order to verify the judicious choice of a formula. Since Schulz measured only a relative excitation, then, in the spirit of Eq. (1) or (2) he measured essentially $a_1/(a_2 + a_3)$. Analysis of his data gives $a_1/(a_2 + a_3) = (4.8 \pm 4.6) \times 10^{-2}$. Our data alone yield $a_1/(a_2 + a_3) = (5.2 \pm 0.9) \times 10^{-2}$, so that we should not incorporate Schulz data into ours. Our more accurate value is obtained mainly because we measured at 90°, where the S-wave term a_1 is greatly increased relative to the P-wave. The data are presented in Table I.

Table I

E_p Mev	E_π(c.m.) Mev	η	θ (c.m.) Degrees	$4\pi \frac{d\sigma}{d\Omega}$ Experimental mb/steradian	$4\pi \frac{d\sigma}{d\Omega}$ Least squares mb/steradian	Over-all correction factor
338	21.5	0.577	30	0.449 ± 0.052	0.470	1.12
338.6	21.7	0.577	57	0.239 ± 0.014	0.249	1.09
338	21.5	0.577	88	0.126 ± 0.021	0.119	1.05
332	19.0	0.540	30	0.423 ± 0.031	0.395	1.18
332	19.0	0.540	60	0.189 ± 0.020	0.202	1.12
332	19.0	0.540	89	0.125 ± 0.0093	0.106	1.13
325	16.0	0.493	79	0.1014 ± 0.0045	0.103	1.27
324	15.5	0.484	89	0.0816 ± 0.0126	0.090	1.20
312	10.4	0.392	90	0.0597 ± 0.0037	0.066	1.45
310	9.52	0.377	55	0.151 ± 0.028	0.107	1.16
310	9.52	0.377	69	0.0819 ± 0.0040	0.080	1.15
310	9.51	0.377	69	0.0869 ± 0.0044	0.080	1.15

From our data alone, the least-squares analysis yields, in units of millibarns per steradian,

$$a_1 = 0.138 \pm 0.015,$$
$$a_2 = 0.200 \pm 0.078,$$
$$a_3 = 2.44 \pm 0.17.$$

With "cross errors",

$$\delta a_1 \, \delta a_2 = -11.2 \times 10^{-4},$$
$$\delta a_1 \, \delta a_3 = 3.83 \times 10^{-4},$$
$$\delta a_2 \, \delta a_3 = -42.3 \times 10^{-4}.$$

These give, in Rosenfeld's notation,

$$\alpha_{10} = a_1 = 0.138 \pm 0.015,$$
$$\beta_{10} = a_2 + 1/3\, a_3 = 1.01 \pm 0.08,$$
$$x = \frac{a_2}{a_3} = 0.082 \pm 0.034,$$
$$\eta c = \left(\frac{a_1}{a_2}\right)^{1/2} = 0.83 \pm 0.21.$$

These measurements have exhibited experimentally for the first time, through α_{10}, the presence of the S-wave mesons in $p + p \rightarrow \pi^+ + d$. It is interesting to note that a very indirect estimate of the S-wave production, which starts from $\gamma + p \rightarrow \pi^+ + n$ and proceeds through many steps to $p + p \rightarrow \pi^+ + d$, yields $\alpha_{10} = 0.14 \pm 0.05$, in excellent agreement with the present direct measurement. The steps are from $\gamma + p \rightarrow \pi^+ + n$ via Bernardini's +/- ratio in deuterium to $\gamma + n \rightarrow \pi^- + p$; via detailed balancing to $\pi^- + p \rightarrow \gamma + n$; via calculation by Brueckner, Serber, and Watson, to $\pi^- + d \rightarrow \gamma + 2n$; via Panofsky's branching ratio for π^- capture in deuterium to $\pi^- + d \rightarrow 2n$; via detailed balancing to $2n \rightarrow \pi^- + d$; and via charge independence to $p + p \rightarrow \pi^+ + d$.

In the experiments with polarized protons, discussed separately below, more information on the S-wave is presented.

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

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

The preliminary result quoted in the last quarterly report was confirmed in a subsequent experiment using a redesigned liquid-hydrogen target, which allowed repeated measurement of the "blank" target. As an interesting corollary it was discovered during the experiment that the 15% "blank" effect observed was almost entirely due to cold hydrogen vapor. The styrofoam target design was such that the proton beam passed through about four times as much length of cold hydrogen vapor as of liquid hydrogen, and since at 20°K 1 atmosphere hydrogen vapor is only about thirty times less dense than liquid hydrogen, a 15% effect resulted. No correction to the asymmetry was necessary. The final polarization results will appear as a letter in the August 15, 1954 Physical Review.

Marshak and Messiah (Il Nuovo cimento, Vol XI, No. 4, 1 April 1954), derived the formula $R-L/R+L = PQ \frac{A \sin\theta}{A + \cos^2\theta}$, where P = proton beam polarization = 0.73 at Berkeley, $A + \cos^2\theta$ is the c.m. angular dependence, and Q is the quantity of interest, involving the relative amounts and phases of S and P waves. In the notation of Rosenfeld's review article (Phys. Rev. to be published),

$$Q = \frac{\sqrt{2}\,\eta c\,\eta}{\eta c^2 + \eta^2} \sin(\psi - \tau_1).$$

Here $\eta = \frac{p_\pi (\text{c.m.})}{m_\pi c}$ and $\eta c^2 = \frac{a_1}{a_2}$, where a_1 and a_2 are obtained from the excitation function at 90° c.m., from $4\pi \frac{d\sigma}{d\Omega}(90^{\circ}) = a_1 \eta + a_2 \eta^3$. Note that in the absence of either S-waves ($\eta c = 0$) or P-waves ($\eta c = \infty$) Q vanishes, and that the maximum possible value of $|Q|$ is 0.71. Our measurements with unpolarized protons (see preceding report) give $\eta c = 0.83 \pm 0.21$. From the asymmetry measurement we obtain $|Q| = 0.39 \pm 0.05$ at $\eta = 0.41$. Combining these, we get $|\sin(\psi - \tau_1)| = 0.70 \pm 0.14$. Here ψ and τ_1 are given by $\delta_o + \sqrt{1/2} = |\delta_o + \sqrt{1/2}| \exp(i\psi)$ and $\delta_1 = |\delta_1| \exp(i\tau_1)$, where δ_o and δ_1 are the complex transition amplitudes for πd production from ^1S_o and $^3P_1$ proton states, respectively, taken relative to the $^1D_2$ proton state, whose transition amplitude is taken as unity. δ_o is written alternately as $\delta_o = |\delta_o| \exp(i\tau_o)$. Gell, Mann, and Watson have shown that, near threshold, τ_o and τ_1 are related to

the p-p scattering phase shifts for the corresponding states by the relations

$$\tau_o = a(^1S_o) - a(^1D_2) + n_\pi,$$

$$\tau_1 = a(^3P_1) - a(^1D_2) + (n' + 1/2)\pi,$$

where the a's are the scattering phase shifts, and n and n' are integers. Thus, the results of the present experiment may be used to put conditions on p-p scattering phase shifts as calculated near 310 Mev.

LIQUID-HYDROGEN GLASER BUBBLE CHAMBER

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

A hydrogen bubble chamber of 4-inch diameter and 2-inch thickness has been completed and is being tested. This chamber has several new features in the design. First, the chamber, in operation, will be a completely closed system. The pressure is controlled with a bellows driven by a solenoid and plunger. This should greatly increase the speed of recycling up to at least several times per second. Further, if one can put the liquid under negative pressure (tension), the strength requirements should be greatly reduced. This is important with regard to thin windows and heat capacity in the design of large chambers. The second new feature is the elimination of the high-pressure liquid-hydrogen bath as an "oven" to control the bubble-chamber temperatures. Instead, a variable helium gas leak will be used to conduct heat to the chamber. This should also be of great value in going to larger chambers. The heat-leak-oven method is a modification of a design used by Roger Hildebrand and D. Nagle at Chicago. The present chamber is intended to be used to measure positive meson scattering on hydrogen at very low energy.

GAMMA-RAY SCATTERING FROM HYDROGEN

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

A new attempt will be made in a few weeks, with an intense source of Ba^{140} γ-rays.

FILM PROGRAM

Walter H. Barkas

Electron and Photon Research

Work on selective scattering of photons by nuclei was continued. The energy resolution obtainable in measuring 6-Mev photons was determined using the line at 6.14 Mev from proton bombardment of fluorine. The standard deviation of the apparent pair energies in 400μ emulsion came out to be 1.37 Mev.

Successful runs were made in attempts to expose plates to high-energy positrons and electrons of accurately equal energies for comparison of their behavior.

Research on Nuclear Processes

The reaction $Li^7 + D \rightarrow Li^8 + p$ has been studied using deuterons of high energy (125 Mev). The absolute differential cross sections at various angles of emission of the Li^8 have been measured, and comparison with the relevant theory is being made. The range-energy relation for Li ions in emulsion has been determined also. To supplement the data on the evaporation spectra of charged particles obtained by bombarding a series of nuclei with high-energy protons, deuterons, and alpha particles, the evaporation spectrum of neutrons from silver is being investigated. The method of observing recoil protons in nuclear track emulsion is being used.

The stripping and disintegration of alpha particles in nuclear interactions has been observed in emulsion and appears to be an important process. Alpha particles of 385 Mev after interaction with a nucleus frequently continue straight ahead, either as one or two singly charged particles.

The interaction free paths in emulsion for low-energy (30.8 Mev and less) protons is also being determined.

Other Work

The study of proton tracks has been undertaken with a view to separately measuring the geometrical range straggling that arises from the scattering of the tracks and the true range straggling. Considerable effort also is being expended in studying the nature of the distortions that occur in emulsion. A computation program is being carried out for the construction of tables relating all measurable quantities in the emulsion.

Publications

The following papers were given at the Seattle meeting of the American Physical Society:

H. H. Heckman, Peter C. Giles, and Walter H. Barkas, "High-Energy Gamma-Ray Studies With Nuclear Track Emulsions".

Walter H. Barkas and George Hahn, "Emulsion Tables".

CLOUD CHAMBER STUDIES

INTERACTIONS OF 28-MEV PROTONS WITH He^4

Arthur W. Wickersham

The reactions of 28-Mev protons and He^4 have been investigated with a cloud chamber placed in the beam of the Berkeley linear accelerator. The following processes were observed:

1. p - α elastic scattering;
2. $He^4(p, d)He^3$;
3. $He^4(p, 2p)H^3$;
4. $He^4(p, pn)He^3$.

Angular distributions were obtained for the first two reactions. Comparison of the yield of the first reaction and of results of other investigators working with the same accelerating machine permits the assignment of differential cross sections to the first two reactions and total cross sections to the remaining reactions.

Analysis of the rest-frame momentum spectrum of protons from the $He^4(p, 2p)H^3$ reaction presents no evidence of an excited level in He^4 in the energy range studied, namely 0 to 23 Mev. The momentum spectrum resulting from such an interaction is a function not only of the transformation matrix appropriate to the interaction but also of the density of available final states, i.e., the available momentum volume. The observed momentum spectrum agrees within the statistics of the measurements with the spectrum expected when the transformation matrix is assumed constant and the momentum volume is corrected for the limited visibility of cloud-chamber photography.

No evidence for the reaction $He^4(p, p\gamma)He^4$ was observed, indicating a cross section less than a few millibarns in this energy range.

THEORETICAL GROUP

David L. Judd

The fringing effects and aberrations of a magnetic spectrometer have been calculated in connection with the design of an instrument that will retain high resolution while permitting the use of relatively wide aperture. Some effort is being devoted to studying focusing in magnetic fields from a global point of view which would not require the detailed integration of the orbit equations to obtain the entire particle trajectory. (S. Bludman)

A method has been worked out for using the differential analyzer to determine parameters in a singular nucleon-nucleon potential model. The possibility of developing a covariant phase-shift analysis for two-body problems by making an operator expansion of the Green's function is being investigated. (H. P. Noyes)

The polarization of 300-Mev protons elastically scattered from aluminum has been calculated and found to agree with the experimental results published by Chamberlain et al. The problem was treated using the optical model with a spin-orbit-dependent nuclear potential.

The optical model potential with a spin-orbit coupling has been expressed in terms of the individual nucleon-nucleon scattering processes. By comparison with S. Tamor's calculation of the polarization of nucleons scattered from nuclei it is shown that the usual tensor force in the nucleon-nucleon interaction leads to an effective spin-orbit potential for the optical model of about 1 Mev and of the same sign as the spin-orbit potential of the shell model. (W. Heckrotte)

The high-energy neutron spectrum produced by protons impinging on complex nuclei is being studied. (E. Vaughan)

Work on the problem of alpha decay to the rotational levels of a spheroidal nucleus is continuing. Calculations are being made of the spheroidal partial waves and their derivatives at the nuclear surface, in preparation for their integration through the barrier by means of the differential analyzer. (B. Segall in collaboration with J. O. Rasmussen of Chemistry)

An investigation on a statistical model for high-energy processes has been completed and submitted for publication in the Physical Review. The possibility of including additional constants of the motion is currently being explored. (M. Neuman and J. V. Lepore)

The angular distribution of the reaction $p + p \rightarrow \pi^+ + d$ may be interpreted as implying that meson production takes place through a virtual nucleon state with spin and isotopic spin 3/2. All reactions $N + N \rightarrow d + \pi + \pi$ (N = nucleon) were studied on the basis of this same mechanism to see if it had any simple implication for the pion angular correlation, but none was found. (R. Spitzer)

An investigation of phenomena in ionized media is being undertaken. (R. Riddell)

The problem of interpreting deuteron stripping by means of a complex potential for the interaction of neutron and proton has been undertaken. (R. Stuart)

Some general focusing properties of arbitrary magnetic fields are under investigation, with particular attention being paid to the possibility of studying aberrations in a general way. (D. Judd, R. Karplus, and R. Stuart)

The polarization of relativistic nucleons is being investigated. (J. V. Lepore)

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

An investigation of meson-nucleon scattering in the intermediate coupling region is being carried out. (R. Riddell and B. Fried)

The angular and energy distribution of photo protons 50-140 Mev predicted by various photo absorption mechanisms is currently being investigated. Results recently calculated for direct emission and results for subnuclear models are being compared with experimental data. (A. Reifman)

The integral equations, obtained by a decomposition scheme applied to the meson-nucleon system, have been shown to be consistently renormalizable within the limits of the approximation in the first few approximations of the scheme. A report of this work is currently being written. (R. Arnowitt and S. Gasiorowicz)

A possible interpretation in terms of magnetic monopoles of the recent narrow-angle, high-energy photon shower observed by Schein has been studied. The origin of the photons is taken to be a collision between an incoming pole with energy $\approx 10^{13}$ ev, electronic mass, and an aluminum atom in the exposure box.

The model leads to a most probable number of pairs to be observed in Schein's length of emulsion of about 30. The observed angular and energy distributions are consistent with this picture. Explanations of this event in terms of purely electrically charged particles appear to be excluded, since a crucial role is played by the strength of the monopole's coupling constant (Dirac's condition that $g^2/4\pi = 137/4$).

A field-theoretical formulation of the interaction of these particles with the Maxwell-Dirac fields is being investigated. (R. Arnowitt and S. Deser)

Studies of beam dynamics in the proposed heavy-ion accelerator have led to the following decisions:

(1) Acceleration will occur in two steps: (a) a "prestripper" of three-fourths inch, employing grid focusing, will accelerate the output beam of a Cockroft-Walton to an energy of 3/4 Mev per nucleon; (b) a "poststripper" of bore tapered from 2 inches to 3-1/2 inches, employing magnetic strong focusing, will further accelerate the ions to an energy of 10 Mev/nucleon.

(2) Between the two sections will be a region of high gas pressure where the ions will have their specific ionization increased, by stripping, from about 0.15 or 0.20 to more than 0.3 of e/m ratio of the proton.

(3) The frequency will be 70 mc; the poststripper will be 91 feet long and contain 70 drift tubes.

Work is now proceeding on the prestripper, with particular attention to the details of the effect of the grids on ion trajectories. Some work is also in progress on the Cockroft-Walton accelerating column, for there is reason to expect some difficulties from space-charge effects. (L. Smith)

ACCELERATOR OPERATION AND DEVELOPMENT

BEVATRON

E. J. Lofgren, Bruce Cork

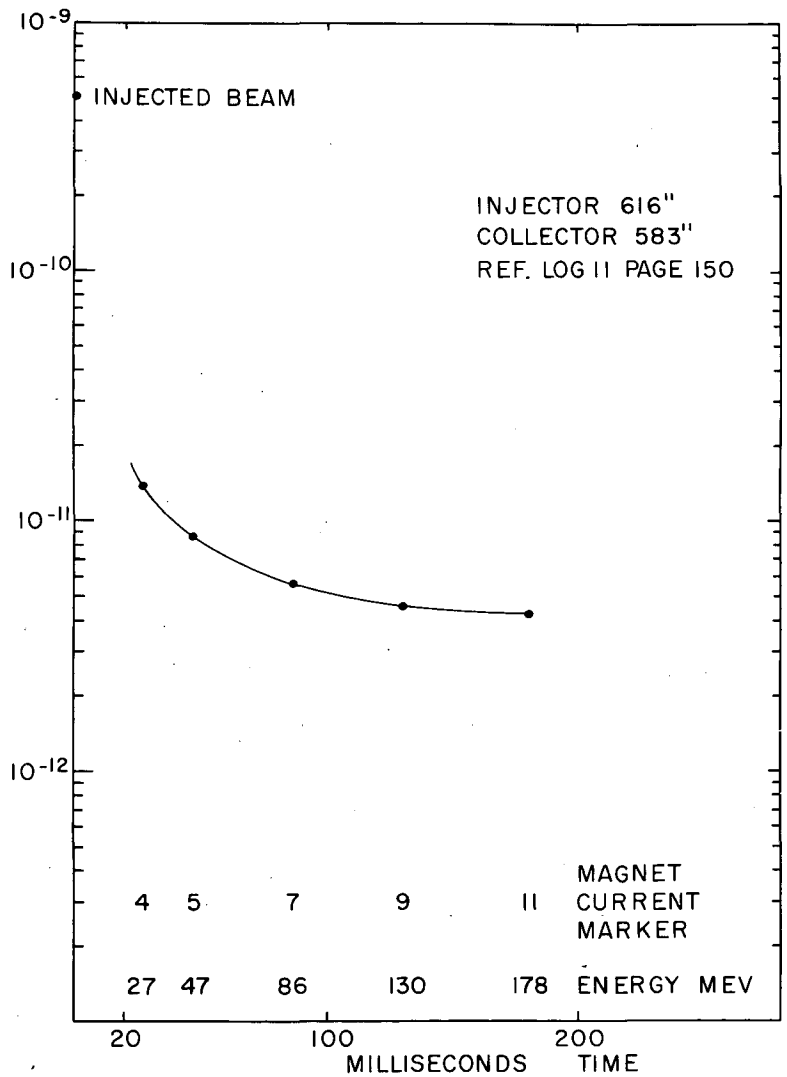
General Operation

By June 25, the rehabilitation of the ignitrons and associated equipment reached the point where it was possible to operate on the west generator. The program of operational adjustments was then resumed. The beam was easily brought to the maximum energy with one generator, 3.5 Bev. The attrition of the beam during acceleration, however, which was characteristic of earlier operation, still prevailed.

Since the first injection of beam, February 2, there have been 9 weeks of nominal operation on two generators, 4 weeks on one generator, and 12 weeks of complete shutdown. The nominal operating time of 13 weeks has averaged about 1/3 effective time, consequently we are not very far along on a program of systematic and quantitative study of the machine.

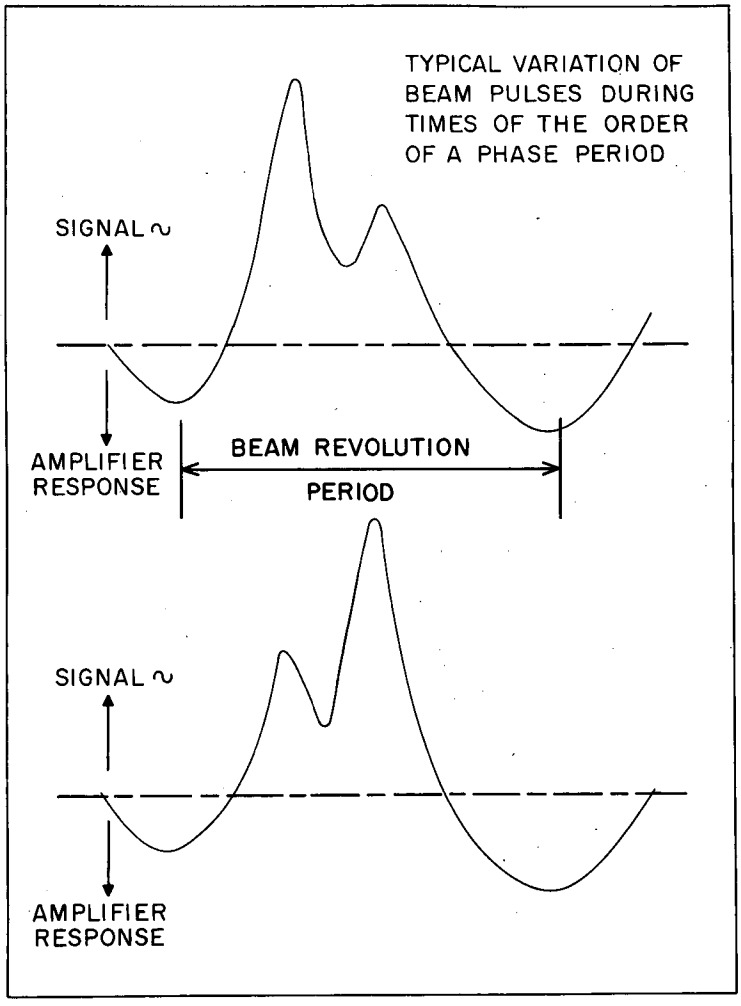
In the energy region below 200 Mev it is possible to intercept the beam on thick copper collectors and measure the current and the duration of the pulse. The injected current at the inflector exit can also be measured and the acceptance time of the machine estimated by comparison with measurements made on the Cosmotron. Data so obtained are good to about a factor of 2. Figure 1 is a plot of best conditions which have been achieved to date. There is a loss by a factor of 10 at injection and by another factor of 10 in acceleration to 150 Mev. No quantitative measurement to higher energies was made at the time, but it is known from previous measurements on photographic plates and from the signal on the pickup electrodes that there is a further loss, by a factor of 10 to 100, in getting to the multi-Bev range.

The signals on the pickup electrodes have been cleaned up to the extent that it is now possible to resolve the shape of the individual pulses as the bunch goes around. Figure 2 is a typical representation. The shape of the pulses is constantly changing in times of the order of a phase oscillation period, suggesting that phase oscillations may be excited by noise in the rf or by defects in the magnet.


10-9
10-10
10-11
10-12
INJECTED BEAM
INJECTOR 616"
COLLECTOR 583"
REF. LOG 11 PAGE 150
4 5 7 9 11
MAGNET CURRENT MARKER
27 47 86 130 178
ENERGY MEV
20
100
200
MILLISECONDS
TIME

MU-8221

Fig. 1


TYPICAL VARIATION OF
BEAM PULSES DURING
TIMES OF THE ORDER
OF A PHASE PERIOD
SIGNAL ~
AMPLIFIER
RESPONSE
BEAM REVOLUTION
PERIOD
SIGNAL ~
AMPLIFIER
RESPONSE

MU-8222

Fig. 2

The beam was measured on the collector at an energy of 28 Mev as a function of tank pressure to verify that there were no abnormal losses. At an average indicated pressure of 1.4×10^{-5} mm, the beam was 1.8 cm (arbitrary, but proportional scale). At 2.3×10^{-5} mm, it was 1.0 cm. The usual operating pressure is 1.0×10^{-5} mm.

Accelerating System

The Radiofrequency Group has built a sensitive detector which compares the phase of a signal from one high-frequency generator with that from some other high-frequency generator. This detector has been used to observe the noise modulation that appears as a phase shift; for example, between the master oscillator and the final amplifier. Noise modulation is here defined as any unwanted frequency or amplitude fluctuations in the rf. Also, comparisons have been made with the driver amplifier and with the induction electrode signal. Numerous sources of noise have been found and reduced in magnitude. It is not yet known which components require further improvement.

Phase oscillations have been excited by applying a fixed frequency modulation to the accelerating drift tube. The synchrotron phase-oscillation frequency is approximately 2200 cycles, near injection. An audio oscillator was used to modulate the variable current supply for the ferroxcube saturable reactor. A few degrees of phase modulation was sufficient at the phase-oscillation frequency to lose all of the beam. At frequencies 20% greater or less than the phase-oscillation frequency, approximately 20° phase modulation was required to lose the beam. Further work is being done to measure the effects of noise modulation, and to improve the frequency tracking.

Injector

The new linear accelerator preexciter using an Eimac 4 W 20,000 tetrode oscillator operates quite well. Greater stability results because of improved design. The output power is approximately twice that of the old radar oscillators and no sparking occurs in the oscillator.

A 200-megacycle resonant cavity has been placed between the 480-kev Cockcroft-Walton generator and the linear accelerator. Energy is coupled from the main resonant cavity of the linear accelerator to excite the buncher cavity. Protons crossing the gap of the resonant cavity can gain or lose a maximum of 10 kv energy and drift for a distance of one meter. The buncher has increased the peak accelerated beam from the linear accelerator to 140 microamperes, a gain of somewhat more than a factor of three.

The maximum beam at the exit of the inflector has been 75 microamperes. This is approximately the same fraction of linear accelerator beam as without the buncher, so no significant changes have been made in the divergence of the beam.

Magnet Power Supply

The east generator, which had been damaged in April, has been excited, but has not yet run under load because the outgassing on the ignitrons is not completed. Grid rectox units and coupling transformers have not yet been supplied in sufficient numbers to replace those which failed in both the east and west installations.

Thyrite is being added to each of the ignitron grids to protect the rectox units and coupling transformers against surges. The bias on the inner grid (dc) has been changed from -75 volts to -35 volts. The signal on the outer grid (ac) has been increased in duration from 2 to 3 lobes of the 12-phase ac. A switching arrangement has also been installed, which retards this voltage one lobe at inversion. The standard operating temperature of the ignitrons has been lowered from 43°C to 40°C and is maintained at all times.

The west generator was run for 17 days between June 18 and July 30. Most of the pulses were at 1500 amp and 9 kv. The over-all fault rate was 1710 pulses per fault.

Magnet

The alignment of the magnet has been checked at a few sample stations and it seems to have remained stationary. It is apparent, however, from the

operation of the machine that the misalignment was not a major cause of beam loss.

Vacuum Tank

The vacuum tank is made of 3/64-inch thick stainless steel sealed with clamping bars and gaskets. The joints must also be electrically insulating to prevent induced currents, which could disturb the magnetic field and, in extreme cases, melt portions of the tank.

It has been very difficult to maintain a resistance of several hundred ohms at these joints, because they were not designed to exclude metal chips and because insufficient care was exercised during construction. The most critical components, namely the outer and inner walls and two ends of each curved section of tank, are continuously monitored for electrical resistance and interlocked with the magnet power supply. A program of cleaning up the offending joints and protecting them with insulating tape is under way. Unfortunately the joints are extremely inaccessible, so that it is not practical to do a complete job.

There have also been troublesome grounds in the pole-face windings and their connections.

184-INCH CYCLOTRON

January through July 1954

Modification

Richard Burleigh

Magnet

The auxiliary coils have been received from Westinghouse. The vacuum seals have been welded in place and the coil tanks are now vacuum-tight. The terminal boxes are complete and the problem of making the joints between the coils and the terminal boxes is being studied. Design is proceeding on the leads to the auxiliary coils.

The pole shims, pole extension discs, and pole bolts have been completed. The parts required for reinforcing the main coil supports are also finished.

The contract for the cooling towers has been let and is in suspension pending the determination of the shut-down date.

Radiofrequency System

All the major components of the rf system except the vibrating blades and the permanent transmission lines have been completed and assembled in Building 6 for full-scale rf tests. Preliminary tests with dummy blades and temporary transmission lines indicate agreement with previous model tests. The design of the permanent transmission lines will evolve during further rf tests.

The status of the blades is as follows:

Blades 1 and 2 --	Returned to project after replating (first plating too thick) August 6.
Blades 3 and 4 --	Copper plated. On project being tested.
Blades 5 and 6 --	Returned to project after plating August 6.
Blades 7 and 8 --	On project being tested. To be plated about August 14.
Blade 9 --	On project being prepared for nitriding.
Blades 10 and 11-	At Mare Island being machined. Delivery expected about August 11.

Some trouble was experienced with shorts in the blade motors, necessitating rebuilding. Three motors have been rebuilt and the other two are being worked on.

The stator proximity detectors are complete and installed. The 10% external-inductance system for phase and amplitude control is being developed.

Miscellaneous

The booster pumps for the 20-inch diffusion pumps appear to have insufficient capacity; this problem is being studied. The manifolds for the diffusion pumps are completed but not vacuum-tested.

The detailed design of the deflector has been postponed until a circulating beam is obtained. Work is progressing, however, on associated equipment: the trimming coils are in production, the design for the movable scattering target in the dee is almost complete, and some preliminary design work has been done on the steering magnet.

Design work for the meson cave shielding is complete and design is proceeding on other shielding changes.

Design is progressing on the ion source and miscellaneous minor items.

The probable date for the shutdown is now October 10, but is subject to change depending on bevatron operation achieved by that time.

60-INCH CYCLOTRON

OPERATIONS

G. Bernard Rossi

Alpha bombardments	6.0 hrs
Deuteron bombardments	8.0 hrs
Experiments	10.0 hrs
Operations Total	24.0 hrs
Outage	17.0 hrs
Conversion work	1016.0 hrs
Available Time	1057.0 hrs
Week-end shutdown	1119.0 hrs
Holidays: Memorial/July 4th	32.0 hrs
Total Time	2208.0 hrs

The 60-inch cyclotron was shut down April 19 for alterations. The plans (which were started in November, 1953) were to prepare the machine for operation at higher energies with alpha, deuteron, and proton particles and to provide parameters suitable for increased beams of heavy ions (such as C^{+6}, Ne^{+9}, N^{+6}). By July 28 the alterations had been completed and the machine assembled and tested. External beams of alphas, deuterons, and protons were attained with a minimum of "start up" troubles. The alpha-beam energy, measured by aluminum absorption, indicated a mean energy of 48.6 Mev. This energy figure corroborates our expectations for the new parameters. External alpha beams of 25 microamperes were recorded at 230 kilovolts between the dees; 30 to 40 microamperes of deuterons also were recorded with similar dee voltages. A more detailed report of the changes and results will be submitted at a later date. Bombardments are being scheduled again on the same basis as before the shutdown.

LINEAR ACCELERATOR

James D. Gow

During the three-month period ending July 31, 1954, the linear accelerator and Van de Graaff operated for a total of 918 hours for general physics research. The major portion of this time has been spent on scattering experiments, including some work on polarization effects. The work on gas stripping has continued. The operation time for both machines has been around 90 percent of the possible operation time.

The Van de Graaff auxiliary ion-source gas supply has been filled with helium for one period, and an attempt was made to accelerate He^{++} beams to 32 Mev with the linear accelerator. So far it has proven impossible to produce currents larger than 2×10^{-13} amperes. It is believed that this is the result of the extremely low percentage of He^{++} in the helium beam obtained from the Van de Graaff. Later this auxiliary gas system was filled with neon, and beams of Ne^{++} of adequate strength for stripping experiments were produced.

The problem of relatively poor belt life in the Van de Graaff charging system has been attacked. Observation of the used belts revealed that there was sparking damage, which was most probably caused by arcs between the accelerating tube and the belt. A set of tie bars was provided between the tube sections and the main support structure corona system. These are to assure a more even potential distribution along the tube. Their installation appears to have eliminated this source of trouble. In order to learn the source of various spark damages, a polaroid camera has been arranged to permit photography of sparks through a viewing window. Open-shutter photography is used, with the spark providing the illumination.

The experimental 4 W 20000 pre-exciter was removed from the 40-foot linac and installed on the bevatron 10-Mev injector. It has operated very well on that tank. Since the 10-Mev machine is considerably more difficult to pre-excite than the 40-foot machine, it has been left there. The 40-foot linac is operating on the old pre-exciter system pending final assembly and test of the next 4 W 20000 pre-exciter. The oscillator group has continued to do some work on the main oscillator system to increase the tuning range of the oscillators.

This work is required because the production 3 W 10000 tubes vary considerably in interelectrode capacitance from tube to tube.

During this period considerable building alteration has been under way. It has proven necessary to remove the section of the building that housed the counter filling lab and the pump and gas-handling equipment, to provide adequate road clearance between Bldg. 10 and the projected Bldg. 80. Among the changes made are the installation of a control room to house the main machine control equipment, and a pump room which will receive the equipment formerly housed in the "gas shed". In the course of this equipment moving, a new spark-gap switching system has been built by the group. This will be installed in the new pump room. A shutdown to permit change-over of plumbing and wiring has been scheduled for September 1. During that period certain remote-control features will be added to the main oscillator system that will reduce radiation exposures of the operating crew.

SYNCHROTRON

Robert W. Kenney

During May, synchrotron operation was only fairly good, but operation improved throughout June and July and was very good at the end of this three-month period.

Charles McDonald, J. Anderson, and Robert Kenney completed runs on the triplet cross section in hydrogen at 300 Mev quantum energy, and the results are reported in McDonald's thesis, UCRL-2595. This group also completed work on the total Compton cross section at 300 Mev in Be. The results will be reported shortly.

H. Steiner and J. Jungerman secured additional data for the fission cross section in Bi and U at photon energies below 335 Mev to clear up some uncertainties in the Cal Tech data in this energy region. Results will be reported soon.

A modification of the π-μ gear was tested by G. Repp, R. S. White, and M. Jakobson and later used to observe the reaction $\gamma + P \rightarrow \pi^+ + n$ as a function of meson energy at 180°. Carbon$-CH_2$ subtraction technique was employed. The high-pressure hydrogen target was also used, and the results of the two methods agreed within statistics. This work has been partially completed.

A second modification of the π-μ gear by W. Imhof and V. Perez-Mendez is still in the testing stage. A short run was made to facilitate their test program.

Ryokichi Sagane and Walter Dudziak have used the large spiral-orbit spectrometer to observe π^+ and π^- cross sections as a function of Z at 90° in the laboratory system and for several meson energies. The reactions $\gamma + D \rightarrow \pi^+ + 2n$ and $\gamma + D \rightarrow \pi^- + 2p$ have also been observed at 90°. The π^-/π^+ ratio in D is approximately 1.5, independent of meson energy.

Kenneth Bandtel and Dwight Dixon studied the photodisintegration of the deuteron at high energy, using the liquid-deuterium target. This work was satisfactorily completed and will be reported in Dixon's thesis.

Calibrations of the Cornell and Nunan ion chambers during this period are in good agreement with previous calibrations.

Some characteristics of the new magnetic monitor scheme were checked by Anderson, McDonald, and Kenney by using a temporary mock-up. The detailed drawings for this monitor system are nearly ready for the shop.

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