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PHYSICS DIVISION QUARTERLY REPORT

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Berkeley, California

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I GENERAL PHYSICS RESEARCH

1. Cloud Chamber Program

Wilson M. Powell

Disintegration of Helium by 90 Mev Neutrons. Peter Tannenwald.

The detailed analysis of the events occurring in the cloud chamber is being continued, according to the method described in the last Quarterly Report, UCRL-1474. No qualitative changes have occurred since the first results were reported. However, it has become evident that the deuterons produced in the reaction

$$n + He^4 \longrightarrow d + t$$

fall into two distinct groups. One group of deuterons has low energies (a few Mev) and no preferred direction, while the second group has high energies (of the order of 70 Mev) and comes off predominately in the forward direction. This second group of deuterons is thought to be due to the pick-up process.

More disintegrations will be analyzed so that the results will become statistically significant.

The Positron Spectrum from the Decay of the μ Meson. Harmon W. Hubbard.

The method of investigating the spectrum and the techniques and equipment used are given in UCRL Report No. 1474. The work during this period has continued in the following manner.

All the tracks have been examined and their energy measured twice by different observers. This provides a check on the consistency of the measurements. Fig. 1 is a graph of the number of tracks plotted against the amount by which two measurements of the same track differ from their mean. This shows that on the average, measurements can be repeated to within $\pm$ 1.3 Mev. For the range of interest the radii of curvature are such that, with the 8000 gauss field used, the error in the reproducibility of measurements is very nearly independent of the energy of the electron.

The ionization loss of electrons from 5 to 55 Mev is very nearly constant. The carbon traversed by the positron was measured for 104 cases by projecting the electron track back to coincide with the π meson track with the aid of the stereoscopic projector. (The μ meson has a range of 0.8mm in carbon) The plates are 4.76 mm thick (3/16 in.) and the average distance traversed is 5.9 mm. For this distance the loss varies from 1.8 Mev at 5 Mev to 2 Mev at 55 Mev. This loss was corrected for the Fermi effect.

Corrections in the spectrum due to radiation loss are made according to the Bethe-Heitler theory. For the purpose of plotting the data, the energy interval from 0 to 60 Mev is divided into 10 Mev intervals. One makes the approximation that all the counts in each interval occur at the center of that interval. In the highest interval (50-60 Mev) one then asks for the probability that a 55 Mev electron radiates less than 5 Mev in traversing 5.9 mm

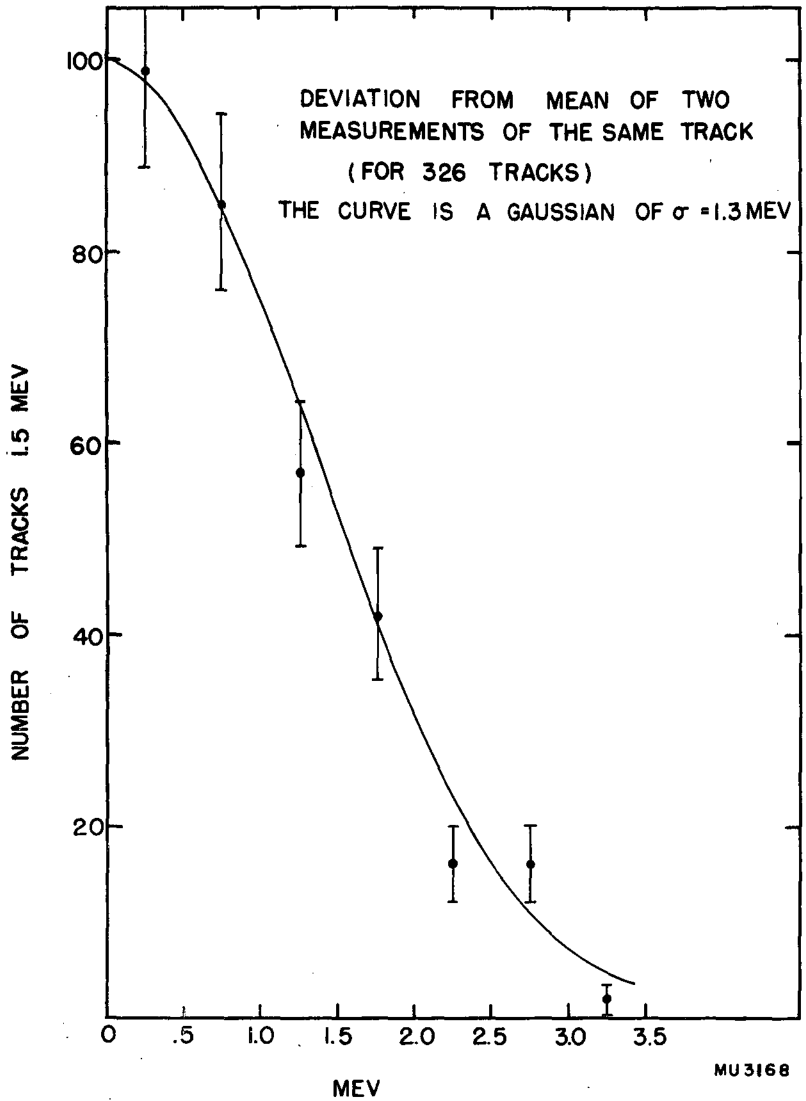
DEVIATION FROM MEAN OF TWO MEASUREMENTS OF THE SAME TRACK
(FOR 326 TRACKS)
THE CURVE IS A GAUSSIAN OF σ = 1.3 MEV
NUMBER OF TRACKS 1.5 MEV
100
80
60
40
20
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
MEV
MU3168

Fig. 1

of carbon. This probability is 96.3 percent. One can then correct the number of tracks in the 50-60 Mev interval by increasing their number by 3.7 percent and then subtracting this gain out of the lower energy intervals into which it was radiated. The next step is a repetition of this process for the 40-50 Mev interval, and this is repeated for each of the others in turn. The largest correction for any point was an increase of 3.7 percent.

The uncertainty in radius of curvature expected from scattering in argon at 1-1/4 atmospheres was calculated on the basis of the theory of multiple small angle scattering developed by Williams and Bethe. The calculation makes use of the r.m.s. scattering angle and therefore yields an average radius of curvature due to scattering. For a track length of 6 cm and an electron energy of 50 Mev, which gives the largest curvature due to scattering, the average uncertainty in radius amounts to 3 percent.

During the runs, pictures were taken periodically in the absence of a magnetic field. The curvature of the tracks in these pictures is an indication of the errors to be expected from gas turbulence. So long as tracks are observed due to particles of high enough energy so that gas scattering is negligible, any curvature of these control tracks can be ascribed to a turbulent motion of the gas in the cloud chamber. One hundred such control tracks were carefully measured with the aid of a precision travelling microscope. It was found that a most probable radius of curvature of 1.5 meters existed due to turbulence. This introduces an uncertainty of 15 percent in the maximum energy and 3 percent at 10 Mev. This is by far the most important source of error. Its effect on the spectrum is shown below.

All theoretical spectra can be found from the formula[1,2]

$$f(E) = \frac{4E^2}{W^4}\left[3(W-E) + \frac{2}{3}\rho(4E-3W)\right]$$

where E = electron energy

W = maximum electron energy $\frac{(M_\mu^2 + M_e^2)C^2}{2M_\mu} \cong \frac{M_\mu C^2}{2} = 53.7$ Mev

using a μ meson mass of 210 m_e.

$f(E)dE$ = probability of a μ decay leaving an electron in dE about E.

$$\int_0^W f(E)dE = 1$$

ρ is a parameter. $0 \leq \rho \leq 1$

This is the spectrum for zero mass neutrinos. By varying ρ one sweeps through all possible theoretical spectra (for spin 1/2 μ mesons). ρ can be expressed as a function of the coupling constants of the interacting spinor fields describing the particles.[1]

[1] L. Michel Proc. Phys. Soc. 61A 514 (1950)
[2] L. Michel, Private communication.

In the above formula the only approximation made (except that inherent in perturbation theory and neglect of coulomb effects) is that $m_e c^2/E \ll 1$. Hence the formula represents the theory for all measurable portions of the spectrum.

To find the effect of the measured turbulence on the shape of the spectrum we need first to find the "resolving power" broadening, i.e., the probability that a positron of momentum p' be measured as lying in an interval dp about momentum p. We call this K(p',p)dp. Clearly

$$\int_0^\infty K(p',p)\,dp = 1.$$

Second, we "fold" this resolution into the theoretical curve f(p). (cp = E for the region of interest). The measured spectrum is then

$$F(p) = \int_0^W f(p')K(p',p)\,dp'.$$

We use the measured characteristic turbulence radius $\rho_t = 1.5$ meters. The measured curvature will then lie between $1/\rho - 1/\rho_t$ and $1/\rho + 1/\rho_t$, and therefore the radius of curvature between $(1 + \rho/\rho_t)^{-1}$ and $(1 - \rho/\rho_t)^{-1}$

The measured momentum corresponding to an actual momentum p will always lie between $P_1(p) = p(1 + p/p_t)^{-1}$ and $P_2(p) = p(1 - p/p_t)^{-1}$. For a field of 8000 gauss $p_t = 360$ Mev/c. The interval P_2-P_1 does not have its center at p, but above p.

We make the assumption that it is equally probable for momentum p' to be measured as p anywhere inside the interval $(P_1' P_2')$.

Then
$$\int_{P_1'}^{P_2'} K(p',p)\,dp = K(P_2' - P_1') = 1, \text{ and therefore}$$

$$K(p',p) = \begin{cases} \dfrac{p_t}{2p_1^2} - \dfrac{1}{2p_t}, & \dfrac{p'}{1 + p^1/p_t} < p < \dfrac{p'}{1 - p^1/p_t} \\ 0 & \text{, otherwise} \end{cases}$$

Hence
$$F(p) = \int_{P_1(p)}^{P_2(p)} f(p') \left[\frac{p_t}{2p_1^2} - \frac{1}{2p_t} \right] dp'$$ represents the folded curve.

The results of measurements of 559 decay positron tracks are shown in Fig. 2.

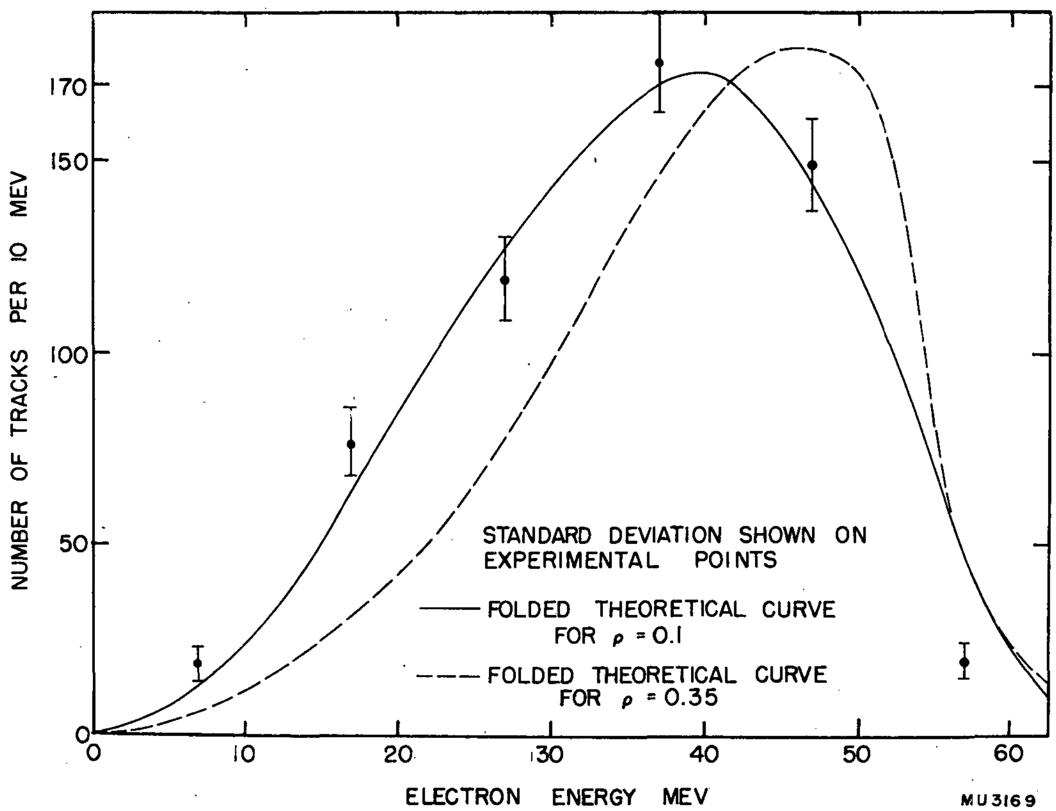
NUMBER OF TRACKS PER 10 MEV
ELECTRON ENERGY MEV
STANDARD DEVIATION SHOWN ON EXPERIMENTAL POINTS
FOLDED THEORETICAL CURVE FOR ρ = 0.1
FOLDED THEORETICAL CURVE FOR ρ = 0.35
MU3169

Fig. 2

Fig. 2 is the energy spectrum, the curves being folded theoretical curves for $\rho = 0.35$ and $\rho = 0.1$. It is seen that the spectrum has a maximum at about 37 Mev. The measured average energy is 34.8 ± 2.5 Mev. Since the theory gives a value $\frac{W}{5}(3 + \frac{2}{3}\rho)$ for the average, this determines a value of ρ, viz. $\rho = .35 \pm .35$. Clearly the poor resolution caused by turbulence makes an accurate determination of ρ impossible. The value $\rho = .35$ is too large to fit the data well as is seen from the figure. (As ρ increases, the intercept at $E = W$ moves from 0 up to a maximum for $\rho = 1$).

There are two reasons for expecting the measured average energy to be too high. The first of these is that any spurious curvature superimposed on the one due to the field favors higher values of momentum, as seen in the folding calculation. We can calculate the magnitude of this effect due to the major uncertainty in curvature, turbulence.

Let the measured average momentum be $\overline{P}$ and the true value $\overline{p}$, then

$$\overline{P} = \int_0^\infty pF(p)dp = \int_0^\infty dpp \int_0^W f(p')K(p'p)dp' = \int_0^W dp'\, f(p') \int_0^\infty dppK(p'p)$$

$$\int_0^\infty pK(p'p)dp = \frac{1}{P_2'-P_1'} \frac{\left[p_2'^2 - p_1'^2\right]}{2} = \frac{P_1' + P_2'}{2} = \frac{p'}{1-\left(\frac{p'}{p_t}\right)^2}$$

$\left(\frac{p'}{p_t}\right)^2 \ll 1$ for all values of p' from 0 to W

Hence $\overline{P} = \int_0^W p'f(p')dp' + \frac{1}{p_t^2} \int_0^W p'^3 f(p')dp' = \overline{p} + \frac{\overline{p^3}}{p_t^2}$. From f(p) we find

$\overline{p^3} = \frac{2}{7} W^3 (1 + \frac{2}{3}\rho)$. This yields

$$\overline{p} = \overline{P} - 0.342\ (1 + \frac{2}{3}\rho)$$

This lowers the average energy only slightly more than 1 percent.

The second reason for expecting $\overline{P}$ to be too high is the fact that since the positrons are observed merging from the surface of a plate in a magnetic field, the solid angle available to a positron decreases with energy. Hence a larger percentage of low energy electrons have been lost than those at comparatively higher energies. 320 of the tracks have been separated into two groups: those making an angle on emerging from the plate of more than 45° to the plate and those making less than 45°. No low energy electrons will be lost from the first group, hence a study of the distribution in this group gives an indication of the magnitude of this effect. The average energy of the first group is 33.6 ± 2.5 Mev and the corresponding $\rho = 0.11 \pm .35$. This effect is therefore an important one, and the data are being further analyzed to enable it to be corrected more precisely.

2. Film Program

Walter H. Barkas

The work of the film group has encompassed a variety of studies, particularly on mesons and fast electrons. Results have been obtained on individual projects as follows:

High Energy Electron-electron Scattering. Charles E. Violet, F. C. Gilbert, Robert W. Deutsch and Walter H. Barkas.

Eradicated electron sensitive nuclear emulsions were exposed to 200 Mev electrons obtained by magnetic analysis of pairs converted in the synchrotron beam. By following primary electron tracks in the emulsion, 427 electron-electron scattering events were recorded in which the scattered electron of lower energy, or knock-on electron, had an energy greater than 30 Kev. The knock-on energy was determined by measuring either the range or the angle between the knock-on and primary tracks. The observed absolute differential cross-section, as a function of knock-on energy, was found to be consistent with Miller's theoretical cross-section. At this primary energy, a sufficient number of events of large fractional energy transfer could not be observed to detect exchange, spin, and retardation effects, and actually only the classical relativistic theory was verified. Two pairs initiated by primary electrons and two cases in which primary electrons vanished in the emulsion were also observed in 102.6 cm of track. No heavy particle events were observed. Fig. 1 is a microphotograph mosaic of an electron-electron collision of large energy transfer initiated by a primary electron of 185 Mev. Fig. 2 is a microphotograph mosaic of an electron-positron pair apparently produced in the field of a nucleus by an electron of about 185 Mev. Fig. 3 is a microphotograph of the unexplained disappearance of an electron of about 185 Mev near the middle of a layer of nuclear emulsion. Fig. 4 is a histogram of experimental electron-electron collision cross-section.

Range straggle of μ^+ Mesons. F. M. Smith, W. Birnbaun, and W. H. Barkas.

The present study is being conducted on the monoenergetic μ^+ mesons arising from decay of π^+ mesons stopping in photographic emulsion. In 200 micron emulsion ~ 17 percent of these μ's will lose all of their kinetic energy in the film. The track lengths of those μ mesons which visibly stop are measured

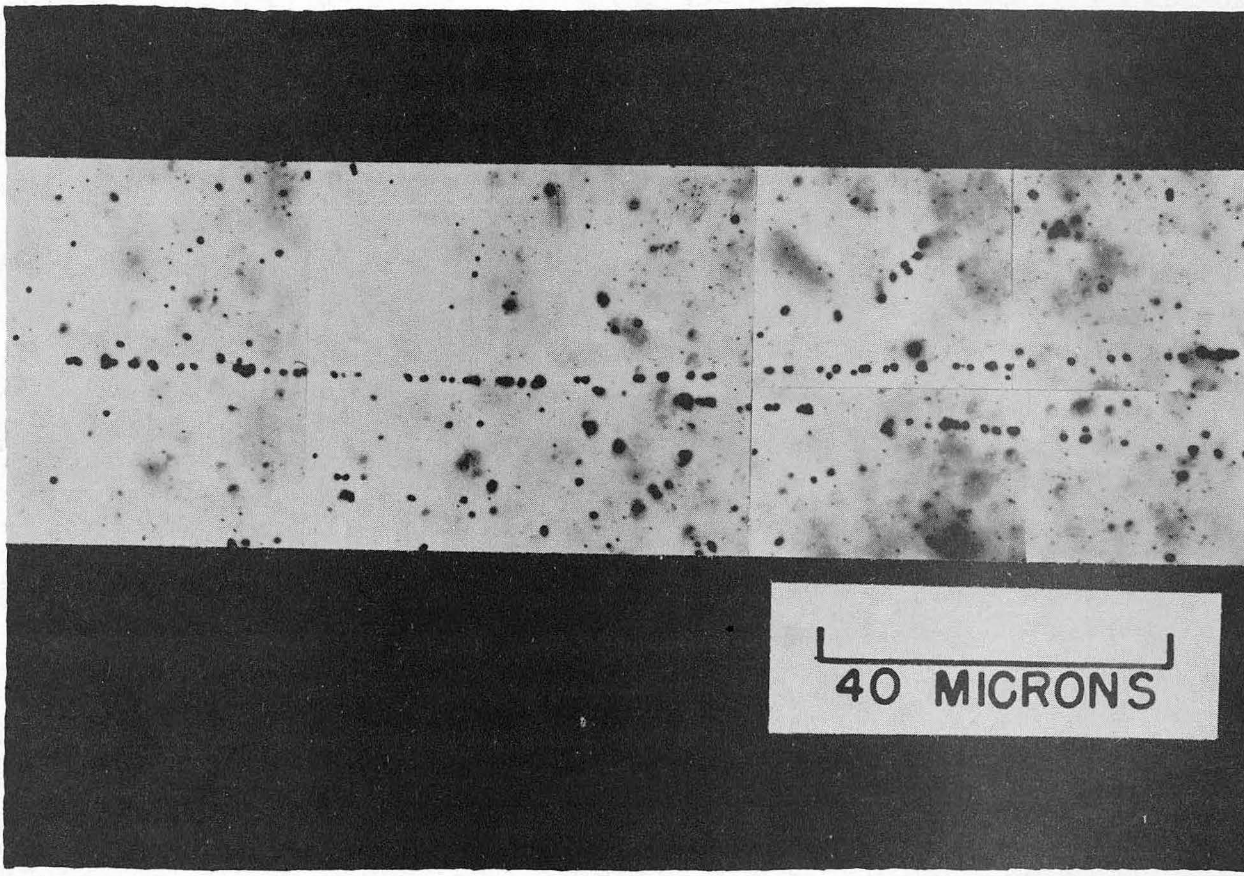

Fig. 1

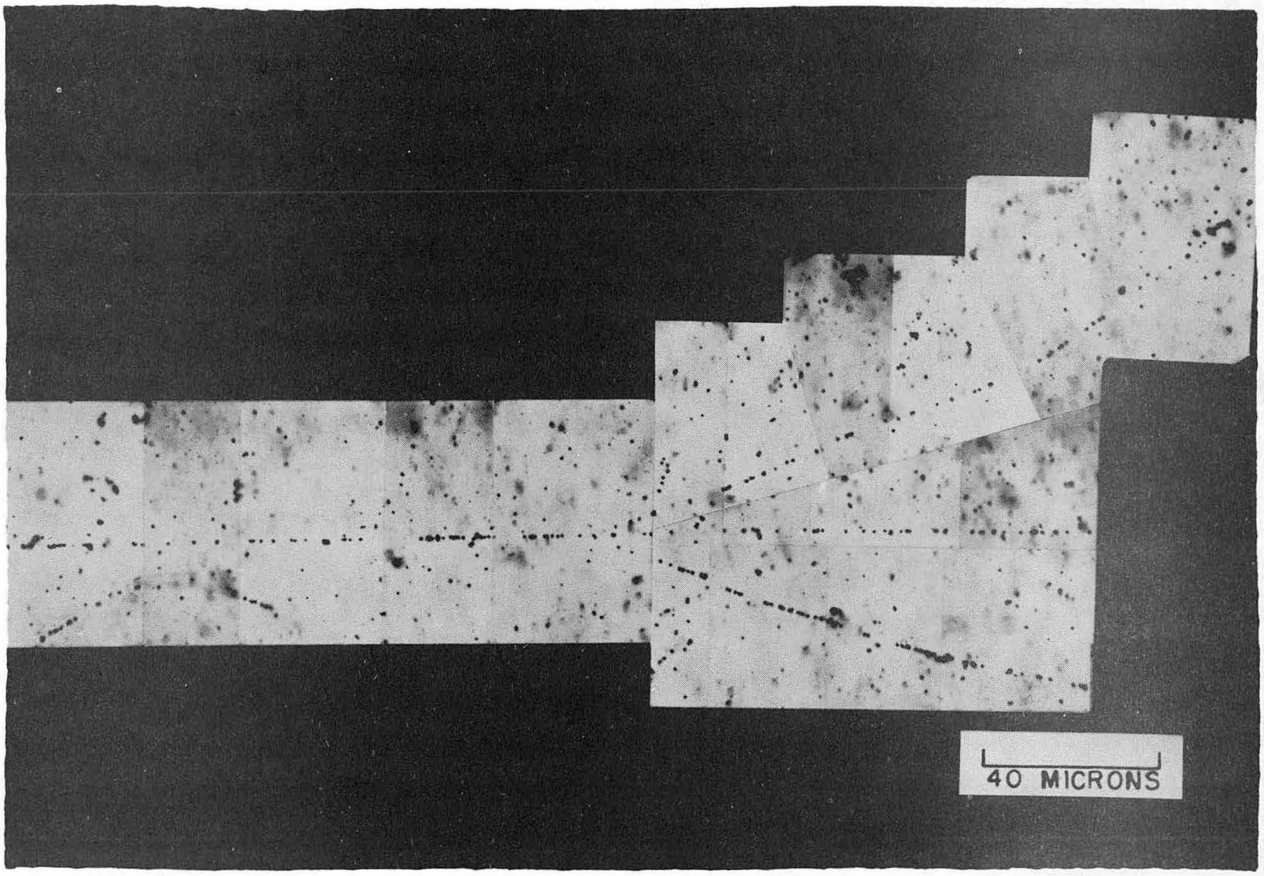

Fig. 2

with regard to total range. The shrinkage factor of the processed film has been determined in order to find the proper depth component of the range.

Preliminary results on the range distribution of 260 tracks are in good agreement with the predictions of straggling theory: The standard deviation of the range is found to be 4.4 percent, and the distribution is not inconsistent with an assumption of normality.

Recent reports[1,2,3] indicate the existence of μ tracks of very short range. Although some of these might conceivably lie within the tail of the distribution, others are too far out to be included and presumably must be attributed to another process.

Fig. 5 is a microphotograph of the decay of a π meson in which the range of the μ meson is much less than normal.

Capture of μ^- Mesons in Nuclear Emulsions. D. F. Sherman, Harry H. Heckman, and Walter H. Barkas.

The behavior of μ^- mesons produced in the cyclotron has been investigated to verify deductions from cosmic ray studies. A beam of μ^- mesons has been obtained inside the 184-inch cyclotron by bombarding a Be target with the proton beam. Because many of the π mesons so produced disintegrate near the target, the target region acts as a diffuse source of μ mesons. A channel was constructed to select a beam of negative mesons of momentum 130± 3 Mev/c. An absorber which stops the π mesons of momentum up to 140 Mev/c was placed in this beam, and an Ilford C-2 emulsion in a wedge absorber was placed behind it to detect μ^- mesons which penetrated the absorber. μ^- mesons were found ending in the plate with a density of about 4000 per cc. in the energy interval 54 to 70 Mev. About 6 percent of these form one prong stars of low energy. This agrees with results of George and Evans[4]. An additional 35 percent show evidence of nuclear capture in the form of two pronglets, each about a micron long, or a "blob" at the end of the track.

Scattering of Negative π Mesons in Aluminum, Copper, and Lead. Harry H. Heckman and Walter H. Barkas.

A new technique is being used to measure nuclear scattering cross sections of π^- mesons as they traverse a semi-infinite scatterer. A stripped nuclear emulsion is embedded in the scatterer, exposed to an incident beam of 50^{+15}_{-5} Mev π^- mesons, and scanned. Most of the mesons stop at the expected

1 W.H. Barkas, Invited paper, Washington meeting of Am. Phys. Soc. (April 1951) - also UCRL-1285

2 W. F. Fry, Phys. Rev. 83 , 1268 (1951)

3 E. Gross, private communication

4 E.P. George and J. Evans, Proc. Phys. Soc. A, 44 , 193 (1951).

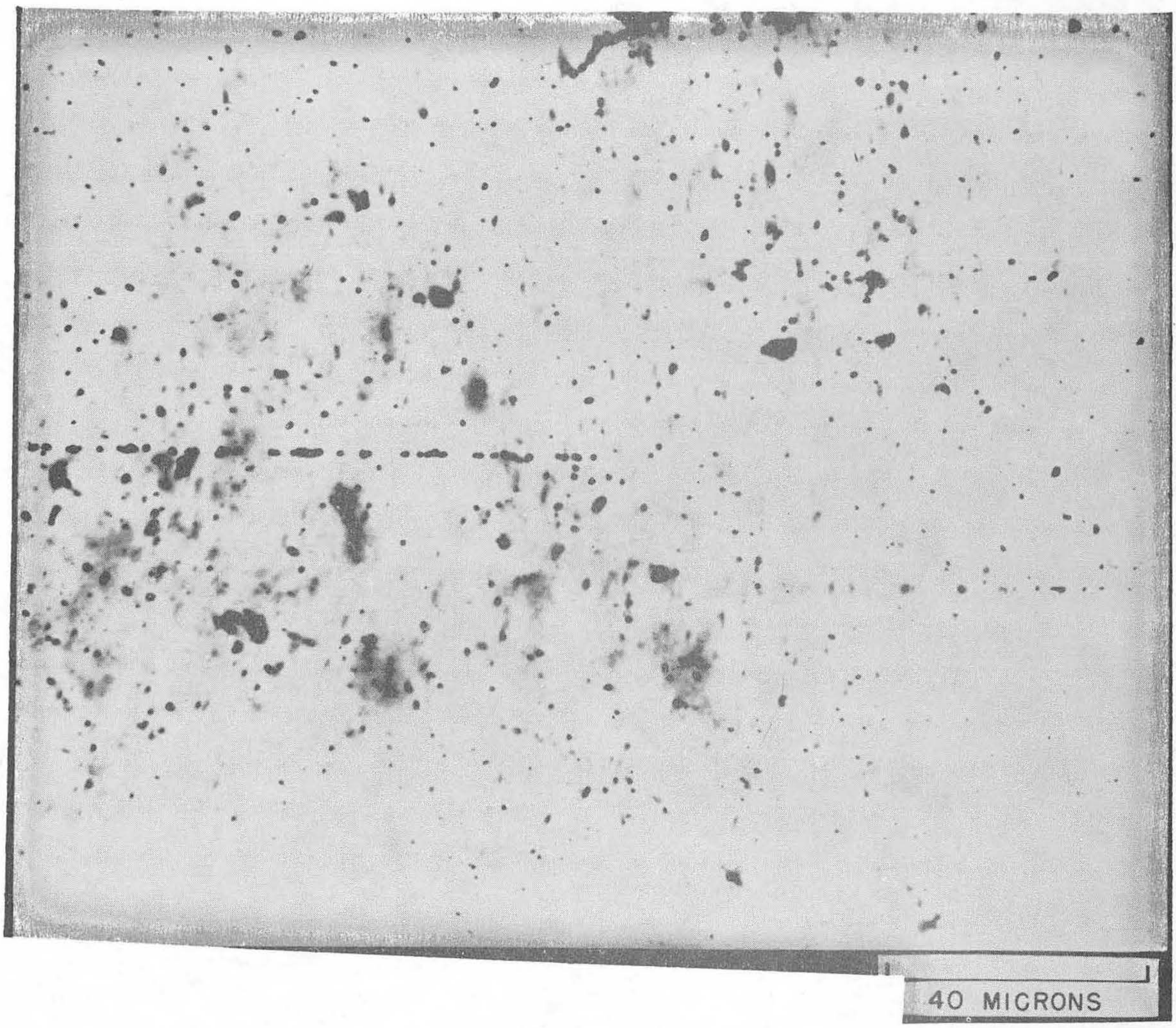

Fig. 3

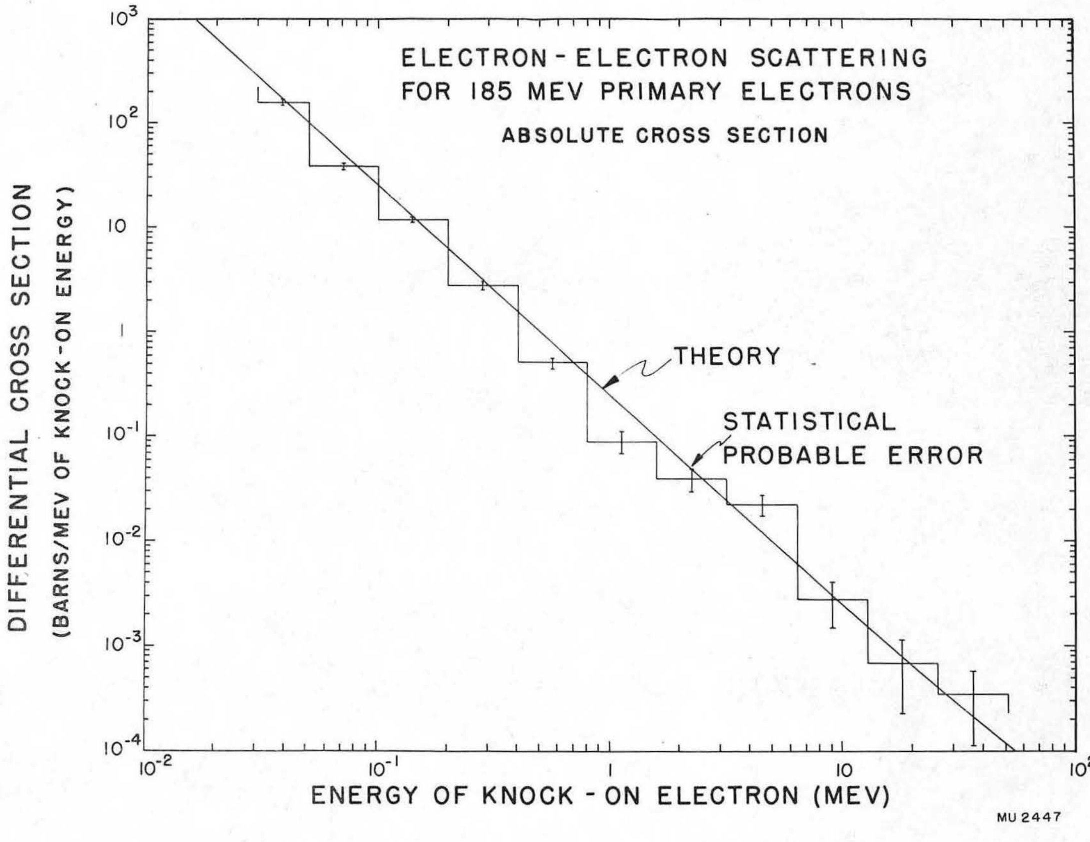
ELECTRON - ELECTRON SCATTERING
FOR 185 MEV PRIMARY ELECTRONS
ABSOLUTE CROSS SECTION
THEORY
STATISTICAL
PROBABLE ERROR
DIFFERENTIAL CROSS SECTION
(BARNS/MEV OF KNOCK-ON ENERGY)
ENERGY OF KNOCK - ON ELECTRON (MEV)
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-2}
10^{-1}
1
10
10^2
MU 2447

Fig. 4

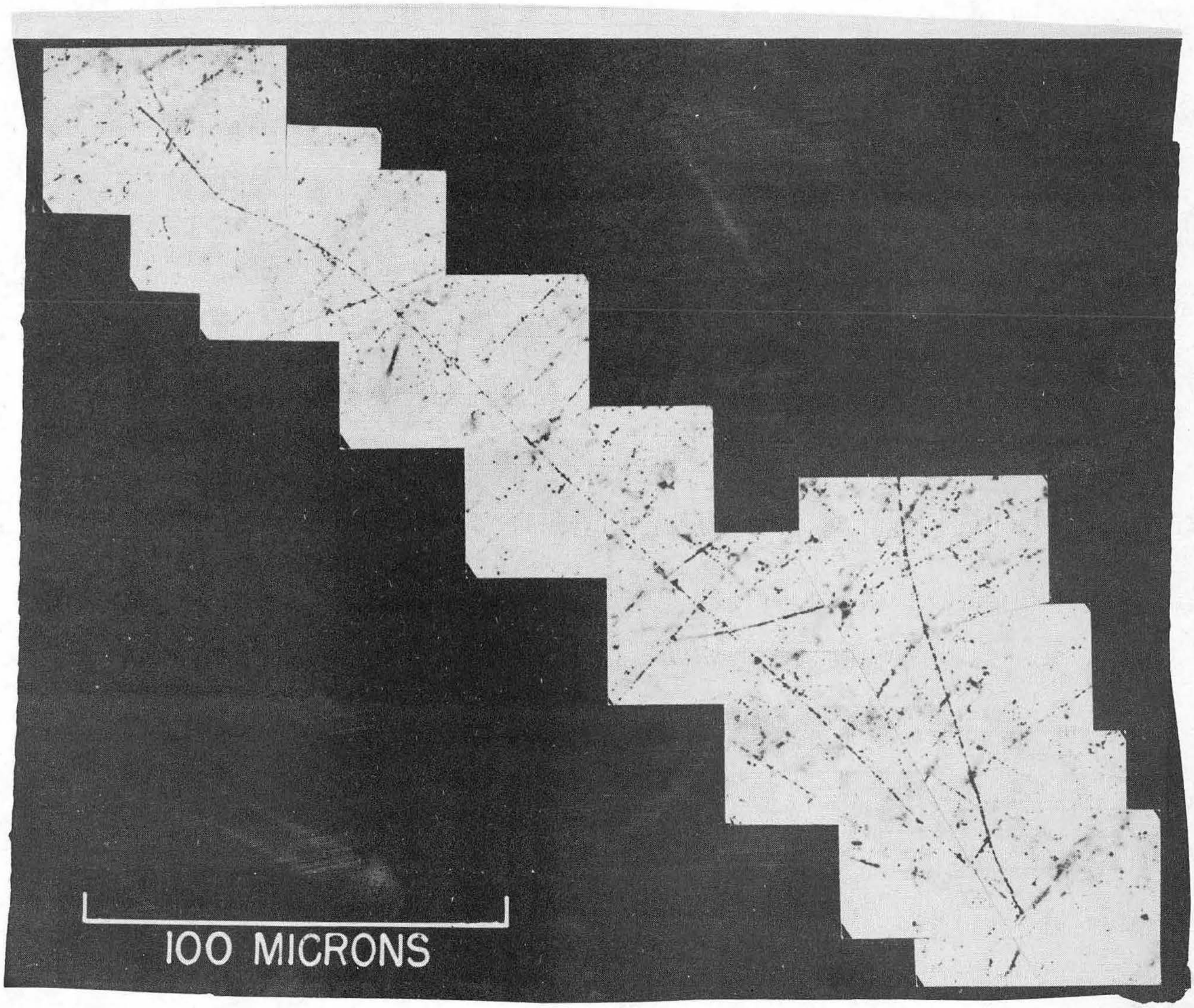

Fig. 5

distance from the absorber edge as determined from the range-energy relation. A few mesons are found at smaller depths of penetration and are attributed to large angle scattering. Mesons travelling opposite (90°-180°) to the direction of the incident beam are attributed to nuclear scattering and are used in the cross section calculation. The assumptions in this calculation are: (a) spherically symmetric nuclear scattering, and (b) nuclear scattering cross section independent of meson energy from 30-60 Mev. There is no geometrical correction factor, i.e., the cross section is proportional to the ratio of the backward flux to incident flux, both of which are observed in the same strip of emulsion. The analysis does not distinguish between elastic and inelastic scattering. The total (elastic and inelastic) nuclear scattering cross section for π^- mesons in the energy interval 40^{+20}_{-10} Mev is being studied for Al, Cu, and Pb. A preliminary value for Cu is 560 ± 160 mb..

Electron Pickup by Fast C^{12} Nuclei in Emulsion. Peter C. Giles and Walter H. Barkas.

C^{12} particles, accelerated in the 60-inch cyclotron to about 120 Mev, were detected by D-1 nuclear emulsion plates which were subsequently developed in D_{19} developer. Measurements were taken of the gap density,[1] as a function of the residual range, on 223 particle tracks. It was noticed that the gap density passed through a minimum at a residual range of about 35 microns, where it is assumed that electron pickup begins. By comparing points on the terminal side of the electron pickup point with points on the initial side of the pickup point of equal gap density, the charge on the particle was estimated as a function of the residual range. It was assumed that the rate of energy loss may be determined from $dE/dR = Z^2 f(V)$, where $f(V)$ is determined from proton data, E is the particle energy, R the residual range, and Z the instantaneous value of the charge carried by the ion.

Some Differential Analyzer Methods for Orbit Problems in the Cyclotron. Bayard Rankin, John Killeen, and Walter H. Barkas.

The equations of motion for a charged particle in the magnetic field have been solved previously in some special cases[2]. These solutions almost always lead to numerical methods. However, the median and vertical plane motion for any axially symmetric field can be obtained quickly on a differential analyzer after transforming the equations by a few simple devices. Only resets on the integrands are required for each set of initial conditions, and an orbit can be drawn every five minutes.

The horizontal motion is solvable on an analyzer of six integrators and three input tables. It is necessary simply to introduce the variable

$\lambda' = \varphi' + \frac{eH}{mc}$ in the equation $\dot{r} = \int r\dot{\varphi}\, d\left[\int \lambda' dt\right]$ and effect a transformation which leaves the relativistic mass independent of the initial conditions without changing the momentum.

1 P.E. Hodgson, Phil. Mag. 41, 725 (1950); also J. K. Bowker, J. Green, and W. H. Barkas, Phys. Rev. 81, 649 (1951)

2 e.g. Norman D. Coggeshell and Morris Muskat, Phys. Rev. 66, 187 (1944) and Walter H. Barkas, Phys. Rev. 78, 90 (A) (1950).

The vertical motion is handled similarly but demands more integrators. An approximation to the vector potential is necessary.

Of special interest are the paths of 30-100 Mev π mesons which are produced in a target at a radius of 80 inches in the 184-inch cyclotron. 200 of these have been obtained on a selsyn driven analyzer by using the methods described. Various focusing points have been examined at seven different energies.

Physical Measurements on Nuclear Photographic Emulsion. A. J. Oliver and Walter H. Barkas.

Calculations of the stopping power of nuclear photographic emulsion and of the volume of emulsion at the time of exposure may be made with more accuracy if the dependence of density and thickness upon relative humidity were known in more detail than is available in published specifications.

A device has been developed for measuring the expansion of emulsion with measured increases of relative humidity, both for unprocessed and for processed plates. The measurement of thickness without distorting soft emulsion at relative humidities from 10 percent to 90 percent was the primary contribution of this work. A second project was the measurement of average thickness and weight for the derivation of a density vs. relative humidity relationship. A third measurement was a check of the refractive indices of emulsion and of the immersion oil employed, so that depth measurements with the microscope are calibrated properly. Measured shrinkage factors were found to vary between 1.8 and 3 depending on humidity conditions.

The emulsion measured was Ilford type C-2, and the processing included fixing and hardening in Kodak Acid Fixer. A chart has been worked out to be employed in determining thickness at exposure, given final thickness and the relative humidities before and after processing.

3. Elastic and Inelastic Scattering of 300 Mev Neutrons by Various Elements

Wm. P. Ball, Burton J. Moyer and Robert E. Richardson

This experiment has been outlined and the equipment described in the preceding Quarterly Report, UCRL-1474.

The equipment for the experiment has now been assembled and bench-tested. It has been decided to use wolfram absorbers rather than uranium for energy discrimination.

In order to determine the detection efficiency of the telescope as a function of angle, it is proposed to make a calibration run in the external proton beam. Aluminum absorbers will be inserted in the beam before the focusing magnet in order to select the proper proton energies for the tests.

4. Short-Lived Products of 90 Mev Neutrons on Carbon

D. A. Kellogg and B. J. Moyer

A third run was recently made with the spinning polyethylene disc method to determine the cross section for the reaction C^{12} (n,p) B^{12} by comparison of the B^{12} beta activity with the C^{11} beta activity formed simultaneously by the reaction C^{12} (n,2n) C^{11}. Increased beam size and intensity plus improved counter operation combined to give higher counting rates than were obtained in the two previous runs. The half-life of B^{12} activity as determined by counting at progressive angular positions on the disc checks with the published value of .022 seconds, but further work is needed to determine whether consistent excess activity found on the first point of the half-life plot is due to experimental error or to an additional half-life of approximately <.005 seconds.

The counting rate of C^{11} positron activity is now sufficiently high to warrant using the rotating disc here also, instead of stopping the disc to concentrate the activity at one point. This is desirable because it eliminates the ratio of irradiated zone to total effective counting zone from the computations.

Variation of beam size and irradiated zone in the three runs seems to indicate that the relative effective counting geometry for the 12 Mev B^{12} and 1 Mev C^{11} betas does not introduce any important error. However, the progressive buildup of C^{11} activity during B^{12} counts necessitates running the experiment on a rigid time schedule, followed by extensive computations to subtract out this activity.

In general, the four complete sets of data obtained in this last run (two discs, two sets of counters) seem to be free of gross random errors to the point of permitting analysis of the systematic errors. A preliminary value of the cross section for C^{12} (n,p) B^{12} is computed to be 9 ± 2 millibarns on the basis of a 22 millibarn cross section for C^{12} (n,2n) C^{11}. However, the latter value is published as 22 ± 4 millibarns, so a larger absolute error is possible in the B^{12} value.

5. The Photoproduction of Negative Mesons from Deuterium

R. Madey, K. Bandtel and J. Frank

Another run has been made at the synchrotron in an effort to obtain the angular distribution of negative pions from deuterium. Pion-proton coincidences were looked for at pion laboratory angles of 90° and 120°. The angle of the proton telescope was varied seven degrees each side of the associated correlation angles; these correlation angles are predicted from the conservation laws for the photoproduction of negative pions from a free neutron at rest. The difference in the counting rates between heavy water and ordinary water show a well-defined peak at the predicted proton angles of 31.5° and 20°. The low counting rates do not permit any firm conclusions to be drawn about the relative yields at these two points.

The instrumentation was changed from the previous run in an effort to improve the statistical accuracy. A third scintillation counter was added to each telescope in order to take advantage of the energy correlation of the production process from a very loosely bound neutron in deuterium. The production of negative pions and protons from the tightly bound neutrons in oxygen is less likely to show both the proper angular and energy correlations simultaneously than the production from a nearly free neutron. Hence, the third counter was used as an anti-coincidence counter to discriminate against particles which have energies greater than that expected for the production of pions and protons from a nearly free neutron. Absorbers were adjusted to limit the photon production energy to 300 Mev for processes surviving anti-coincidence. A comparison of the heavy water vs. ordinary water difference counting rate produced from photons greater than 260 Mev with that from photons in the energy interval from 260 Mev to 300 Mev showed a noticeable improvement in statistical accuracy. Absorption of protons in the target is the chief factor which prevents looking for processes from photon energies lower than 260 Mev in the bremsstrahlung spectrum.

6. Neutral Meson Program on the 184-inch Cyclotron

Walter Crandall, Richard Hales, R.H. Hildebrand, Richard Madey and B.J. Moyer

A pair spectrometer with 14 positron energy channels and 14 electron energy channels, feeding a 14 square coincidence circuit and producing 27 separate gamma ray energy channels, has been used to analyze the spectra emitted from carbon targets for the proton energy and angles of view shown in Table I.

Table I

E_p	θ
345 Mev	$0^\circ, 47^\circ, 90^\circ, 133^\circ, 180^\circ$
285 Mev	$39^\circ, 141^\circ$
245 Mev	$32^\circ, 148^\circ$
185 Mev	$2^\circ, 178^\circ$

If one postulates that the observed gamma radiation originates solely from the decay of a neutral pion then the total gamma ray spectrum, obtained by integrating the observed spectra over the complete sphere, should be symmetric with respect to the log (W_γ/W_o) where W_o is half the rest energy of the neutral pion. The total spectrum appears to be slightly assymetric and requires at least 2 ± 1 percent nonneutral pion gamma radiation. If one neglects this nonneutral pion radiation, the energy distribution of the neutral pions can be obtained from the total spectrum by differentiation. This has been done and the resulting spectrum is similar to the spectrum obtained for charged pions.

7. π Meson Production from Carbon at 90° to the 280 Mev Neutron Beam

Lee Neher, James Carothers, Dwight Dixon

The detection of charged π mesons produced by the 270 Mev neutron beam of the 184-inch synchrocyclotron has been accomplished using a time of flight-velocity detector combined with range and momentum measurements.

Preliminary work at 90° has been done on the measurement of the ratio of negative to positive mesons from carbon and on the energy spectrum of the negative π mesons.

The ratio work was done with a magnet which gave charge and momentum selection. A measurement of the particles' velocity is then sufficient to identify the mesons. Data taken thus far gives a minus to plus ratio of 17 ± 9. This is in general agreement with the photographic work of Bradner, O'Connell and Rankin (UCRL-684) which gave 12.6 ± 1.5. The statistics are determined in both cases by the very low positive production. Our observed π^+ counting rate is of the order of two per hour. Since the ratio is large, we assumed that an energy spectrum obtained with velocity and range only would be essentially a π^- spectrum. The data is very meager due to poor statistics and energy resolution, but there is indication of a peak in the range 35 to 55 Mev and a slow decline in numbers out to 100 Mev.

Throughout these preliminary experiments we have observed high energy protons from carbon at 90° to the neutron beam. The numbers of these at 200 Mev are in the order of the number of mesons and we believe protons up to 250 Mev are present. At 100 Mev they are approximately 10 times the number as at 200 Mev.

Further work on these problems is in progress.

8. Internal Momentum Distributions of Deuterium and Carbon Inferred from Scattering of 340 Mev Protons

J. B. Cladis, W. Hess, B. J. Moyer, J. Wilcox

The energy distributions of protons scattered from deuterium and from carbon at angles of 30° and 40° have been obtained by means of the 35-channel magnetic particle spectrometer. This spectrometer has been described in previous reports. The resolving power of the magnet channels near the peaks of the spectra (250 Mev at 30°, 175 Mev at 40°) were about 11 Mev.

Scattered proton spectra reflect the momentum distribution of the nucleons of a particular nucleus in a rather straight forward manner if the assumption holds that a good majority of the protons are scattered in single collisions with the individual nucleons of the nucleus. That this is probably the case in light nuclei and at the selected scattering angles where interference effects (coulomb scattering, nuclear diffraction scattering, exclusion principle prohibiting small momentum transfers) are small, is upheld by considering that (1) the wave length of 340 Mev protons is comparable with the dimensions of nucleons, and (2) the mean free path of such a proton in nuclear matter is of the order of the dimensions of light muclei. Moreover, as would be expected, the proton yields (obtained from the four-fold proportional counter signals coincidences providing the G.M. tube amplifier gates) from deuterium relative to those from hydrogen at 22°, 30°, and 40° indicate that the constituent nucleons of the deuteron might behave essentially as unbound particles possessing momentum, in contributing to the scattering.

For nuclei for which the above assumption holds, P.A. Wolff has developed a formula giving theoretical scattered proton spectra as functions of scattering angle and nucleon momentum distributions.

The experimental proton spectra from deuterium at 30° and at 40° correspond well with theoretical curves obtained by inserting into Wolff's equation the momentum distribution of the deuteron that is obtained from the fourier transform of its e^{-ar}/r wave function. Since this wave function is assumed to hold near the origin, its transform certainly predicts too many high momentum components. It is quite likely that the fit to the data is good only because a preponderance of the high momentum contributions is manifested in the "tails" of these spectra where the data are not well known. This is unfortunate since a knowledge of these high momentum components is just what is necessary to shed light on the wave function that exists within the strongest part of the interaction potential.

The proton spectra from carbon at these angles are fitted quite well by the theoretical spectra obtained by assuming a gaussian momentum density distribution having a momentum at 1/e that corresponds to a nucleon energy of 16 Mev. It is of interest to note that the fourier transform of this momentum function leads to a gaussian position density distribution that is contained, within its 1/e values, in the "nucleon volume". To be more explicit, if p_r and x_r represent respectively the r.m.s. values of the gaussian momentum and position density distributions, then

$$p_r \, x_r = \hbar/2$$

$$x_r = \frac{\hbar c}{2mc^2 \beta \gamma} \approx \frac{\hbar c}{2mc^2 \sqrt{\frac{T_r}{2mc^2}}} = \frac{1.14 \times 10^{-13}}{\sqrt{2}} \text{cm}$$

Thus, if x is the position at which the value of the gaussian is down by 1/e, then $2x = (2)^{3/2} x_r = 2.28 \times 10^{-13}$ cm.

The Chew-Goldberger momentum distribution contains too many high momentum components to accord with the experimental results.

9. A Study of the Pick-Up Process in Proton Deuteron Scattering

A. Bratenahl and B. J. Moyer

High energy protons, scattered by deuterons, show a small narrow peak in the backward direction. It was proposed by G. F. Chew (Phys. Rev. 74, 809 (1948)) that these protons result principally from rearrangement or "pick-up" collisions in which the incoming proton interacts with the neutron in the deuteron and the neutron-proton pair emerges from the collision into the forward direction as a deuteron. The proton, originally in the deuteron, is left to move in the backward direction with the momentum it possessed in the deuteron at the time of collision. The process is elastic and in the laboratory system the deuteron has a momentum $4/3 \, p_o \cos \theta$, the proton $p_o \sqrt{1 - 8/9 \cos^2 \theta}$, where p_o is the incident proton momentum, θ, the angle the recoil deuteron makes with the direction of the incident proton. A calculation of the differential cross section is particularly simple in Born approximation, depending essentially on two factors: The probability for finding a proton of momentum $p_o \sqrt{1 - 8/9 \cos^2 \theta}$ in the deuteron and the n-p interaction for the appropriate momentum transfer. The latter may be inferred from existing n-p scattering experiments. Thus the pick-up cross section in this view may be regarded as a measure of the high momentum amplitudes in the deuteron wave function. A knowledge of the cross section itself combined with its dependence on incident proton energy can be used as a sensitive test of the correctness of this assumed mechanism.

The cross section and its energy dependence is being measured by a method in which the magnetic field of the cyclotron serves to analyse the high energy particles resulting from proton bombardment of deuterated-paraffin and polyethylene targets. The targets are placed at a radius so as to receive protons of the desired energy and charged particles leaving the target at small angles are detected on a radius line 150° away from the target position. Particles of a given $H\rho$ are detected and identified by causing them to pass through a wedge shaped absorber into nuclear plates. The angles the particle orbits make with the detector probe axis are selected by slit systems placed in front of the absorber. The angles are simply related to θ the angle of departure from the target.

It is found that tracks satisfying the "deuteron condition" regarding $H\rho$ and range are found in numbers exceeding confusable stray background tracks by a factor of ten or more for runs up to twenty minutes. Assuming these particles to be deuteron energies calculated from average observed range and $H\rho$ agree to two per cent over a range of deuteron energies from 70 to 130 Mev. To obtain the deuteron yield from deuterium in the target, it is necessary to subtract the yield from polyethylene. The ratio of net deuteron yield to that from polyethylene at $\theta = 0 \pm 1.5°$ is 0.86 for 110 Mev protons, falling to 0.40 for 150 Mev protons.

So far, only the relative yield in the process at $\theta = 0 \pm 1.5°$ can be reported. For mean proton energies of 95, 112, 130 Mev yields are 1.000 ± .070, 0.869 ± .035, and 0.586 ± 0.061 respectively. Monitoring the incident beam is accomplished by counting the β^+ anihilation radiation from the C^{11} produced in the target. Absolute cross sections will be available when the C^{11} counting set-up is properly calibrated against known proton currents.

Finally, it might be mentioned that the sharp line expected from the elastic p-d process for mono energetic protons, is broadened considerably in this experiment by the spread of proton energies incident on the target. It is found that by clipping the beam vertically to a 1/4 inch aperture multiple passage of the target is greatly reduced but a residual proton energy width remains which is attributable to radial oscillation of the proton orbits of approximately 3 inch mean amplitude. The momentum width of this disturbance seems to be constant as expected over the range of synchronous orbits explored so far, namely 110, 130, 150 Mev but the distribution in amplitude changes. The deuteron yields given above are averaged over these amplitude distributions and the mean energies given, 95, 112, and 130 Mev, compare to synchronous orbit energies of 110, 130, and 150 Mev.

10. 270 Mev Inelastic N-D Scattering

J. B. Cladis, J. W. Hadley, W. Hess

Measurements of the angular and energy distribution of fast protons emitted in n-d collisions have been completed, and will be described in a forthcoming laboratory report (UCRL-1542).

In general, the experimental results indicate that these protons are produced with a distribution in angle and energy similar to that of protons from n-p scattering. Some depression of the n-d proton yield below that from n-p scattering is found, and is thought to result from the effects of the exclusion principle, of the internal momentum distribution of the deuteron, and of the difference in interaction potential between the initial (deuteron + neutron) and final (dineutron + proton) systems in n-d scattering.

11. The Detection of π^o Mesons Produced by the 280 Mev Neutron Beam

Calvin G. Andre

Preliminary data have been obtained on the production of π^o mesons by the neutron beam on targets of C, Al, Cu and Pb. The data which suggest a Z dependence rather than an A dependence, was based on the detection of one of the decay gamma's of the π^o meson. A transition curve obtained with a lead converter gave a peak at about 1/4 inch of lead.

Coincidence detection of the two decay gamma has also been observed but the counting rate is so low as to make difficult its use in studying Z-dependence.

12. Photo Cross Sections in Beryllium

Robert Kenney

The pair spectrometer at the synchrotron has been instrumented for a determination of the total cross section for absorption and scattering of high energy photons by various elements. The non-pair contribution to the total cross section is appreciable in very light elements, and preliminary results for beryllium at 300 Mev indicate this non-pair part to be a few percent greater than the theoretical Compton cross section. Statistics are being improved in order to evaluate this small residual cross section.

13. Proton-deuteron Elastic Scattering using 345 Mev Protons

O. Chamberlain, D. D. Clark, R. Tripp

The first attempts to measure the elastic d-p scattering at this energy have been made with the same counting scheme as was used for d-p scattering with 190 Mev deuterons. This involved simply coincidence counting of the scattered proton and struck deuteron. This method in its simplest form is not proving workable, since the inelastic scattering (involving break-up of the deuteron) is very probable and the angular distribution of the two protons from such a process overlaps the angles for elastic scattering to a large extent.

The methods which will next be tried for differentiating elastic from inelastic scattering will be different in different ranges of angles. At small angles of deflection a separation of effects based on pulse height seems most advantageous since the energy loss by deuterons and protons in one counting crystal are quite different. At intermediate angles it should be possible to use an absorber in front of one crystal to separate the effects, without exceeding about 20 gm/cm^2 of Cu absorber, for which it should still be possible to make a reasonably accurate correction of nuclear absorption. At large angles it is still believed that the original method may be usable, however a test at such angles remains to be made.

It is now becoming evident that the laboratory must obtain more deuteron polyethylene or its equivalent. Present techniques in this experiment are discouragingly limited by the restriction to the one available sample of CD_2, which must be adaptable to work other than this experiment.

A delayed coindicence channel which has now been more or less permanently incorporated in the counting equipment has proved of great usefulness. It allows evaluation of the accidental coincidence rate continously while the measurements are in progress.

14. P-p Scattering at Reduced Energies

John Garrison

The angular range down to 20 degrees (c.m. angle) and the proton energy range 160 to 250 Mev (lab. system) will be studied using a liquid hydrogen target.

The liquid hydrogen target is under construction. It will contain liquid hydrogen in a vertical cylinder of six inch diameter.

Auxiliary equipment such as target supporting table and counter supporting arm are also under construction at this time.

15. Effect of Chemical Binding on Stopping Power

T. J. Thompson

The stopping powers of a number of organic compounds have been measured relative to copper using the 345 Mev proton beam from the 184-inch cyclotron. Not all features of the experiment have been proved reproducible to the extent that will be necessary. Results, still preliminary, indicate that unsaturated compounds have slightly higher stopping powers than saturated compounds of identical atomic constitution.

16. Deuteron-proton Scattering Using 190 Mev Deuterons

A. L. Bloom, O. Chamberlain, M. O. Stern

Reports UCRL-1440 and UCRL-1442 have been written concerning final results of this work.

17. Inelastic Scattering of 32 Mev Protons from the Linear Accelerator

V. Ashby, J. Benveniste, B. Cork, R. Eisberg, G. Igo, and R. Kenney

A search for an excited level of the He^4 nucleus has been made by bombarding a helium gas target with 32 Mev protons and looking for a low energy group of protons among the scattered particles. If such a group is found, it is clear that the excitation energy of the target nucleus is closely related to the energy difference between the incident and scattered protons.

Study of the spectrum of scattered particles has established the identification of a group of low energy particles in the interesting region as deuterons from the reaction $He^4(p,d)He^3$.

A low energy continuum of protons has also been observed. It can be shown that the most important source of these protons is the reaction:

$$p + He^4 \longrightarrow p + n + He^3$$

Study of the data for this part of the spectrum should allow us to calculate a maximum cross section for the formation of a helium nucleus in an excited state.

The investigation of the spectrum of particles scattered from heavy elements, with a view to determining the nature of the processes involved, is continuing. It has already been established that the scattering cross section is not spherically symmetric and hence cannot be a simple "boiling off" process. Furthermore, processes involving the emission of particles heavier than protons may be important, so an adequate investigation dictates that a "particle-namer" be developed. In the scheme which shows the most promise to date, the scattered particle passes through a proportional counter into a NaI(Tl) crystal. The pulse height from the proportional counter is a measure of the rate of energy loss (dE/dx) of the particle, and the pulse height from the photo tube looking at the crystal is proportional to the total energy of the particle. Since the dE/dx of single charged particles of the same energy is practically proportional to their masses, it is expected that the simultaneous measurement of the two pulse heights will yield adequate particle discrimination. Preliminary measurements are quite promising.

The instrumentation for studying the scattering of 32 Mev protons from deuterons has been completed. After forthcoming preliminary tests of the equipment, precision measurements of the differential cross sections for both elastic and inelastic processes will be made.

The design of a completely mechanized apparatus for the extensive and systematic study of inelastic scattering of 32 Mev protons at the linear accelerator is well underway. The final equipment will allow the analysis of spectra of scattered particles with both a differential range apparatus, involving a proportional counter telescope and featuring an automatic, remotely controlled absorber inserter, and a differential energy apparatus using NaI(Tl) crystals and multi-channel pulse height analyzer.

18. Meson Production

Chaim Richman

π^0 Production by Neutrons on Protons. Byron Youtz.

Another attempt was made to look for deuterons produced in the above reaction by an $H\rho$ range separation from the protons scattered from the target. Energy resolution of the equipment had been improved in the hope that distinctive features of the deuteron energy spectrum could be used to identify the π^0 reaction. Again a CH_2-C effect was observed and attributed to deuterons rather than scattered protons, but it was felt that a change in basic method was necessary before the above identification could be made. Redesign of the experiment and building of new equipment is now in progress. Investigations are underway for observing gamma rays from the decay of the π^0 in coincidence with the deuteron as a further identification of the reaction. It is hoped that the improved resolution will also give some information on the high energy n-p capture process.

Meson Production from Protons on Protons at 35^o to the 341 Mev Proton Beam. Marian Whitehead.

In order to complete the investigation of the reaction $p + p \rightarrow \pi^+ + d$, a run was made to measure the production cross section at 35^o to the proton beam in the laboratory. It is expected that these data in conjuction with that at 0° and 60° will give an accurate determination of the constants in the formula:

$$\frac{d\sigma}{d\Omega} = a\left[b + \cos^2\theta\right] \quad \text{(in c.m. system)}$$

which appears to be adequate to represent the angular distribution of the emitted mesons. Preliminary data do not contradict the previous results obtained on the angular distribution.

Low Energy Meson Production from Protons on Protons. O. Heinz

The analysis of the low energy end of the meson spectrum from the reaction $p + p \rightarrow \pi^+ + n + p$ at 0° was continued and preliminary results were obtained. The cross section was measured at 45 Mev and 15 Mev by the standard method using C-3 emulsions and subtracting the carbon yield from the CH_2 yield to get the contribution from hydrogen. At 45 Mev the cross section was found to be 2.2×10^{-30} cm^2/Mev sterad. This is based on 96 mesons from the CH_2 target and 35 mesons from carbon. At 15 Mev the cross section is about $0.34 \pm 0.24 \times 10^{-30}$, but since this result is based on only 28 mesons from CH_2 and 19 from carbon it represents a very tentative value. The high energy end of the meson spectrum from the reaction $p + C \rightarrow \pi^+ + ---$ at 0° to the beam was also investigated by similar methods. The first data obtained points to a very low cross section, of the order of $1/2 \times 10^{-30}$ at 160 Mev.

Meson Production from Carbon at 160° to the 341 Mev Proton Beam. S. Leonard

Nuclear emulsions were exposed to π mesons emerging from a carbon target at 160° with respect to the incident 345 Mev proton beam. In this preliminary experiment, no magnetic field was used, so that π^+ and π^- mesons were registered in the same plate. In this way the production cross sections for π^+ and π^- mesons and the π^+/π^- ratio are being measured at all meson energies. The beam was monitored in the usual way with an argon ion chamber and a beam current integrator.

It appeared from the above preliminary results that the π^+/π^- ratio is rather small, so that it will be necessary to perform this experiment in a magnetic field, using the usual channel techniques, in order to get a sufficient number of π^- mesons for good statistics. Without the field, an exposure great enough to give good π^- statistic introduces too many background tracks into the emulsions for reliable scanning. The measurement in the magnetic field will be of π^- and π^- production cross sections for mesons emitted at 180° to the incident protons.

Meson Production from Deuterons on Carbon at 0° to the 341 Mev Proton Beam. W. Dudziak.

With our goal of measuring the absolute production cross section of (π^+, π^-) meson production from deuterium, resulting from proton bombardment, the first phase, i.e. the measurement of the absolute production cross section of mesons from carbon, was continued. For these experiments, the external 341 Mev deflected proton beam was used. The target was placed in the magnetic field of the pair magnet. In this way, a separation of the charged mesons was obtained. The separated mesons were stopped in C-2 (200 μ) nuclear emulsions. These emulsions after development, were scanned under a high magnification ($\sim$ 600x) and in this way the population of mesons produced by the incident protons was determined. The preliminary results are recorded in Table I. Since the data is being improved, the results are not corrected for nuclear absorption.

Table I

$\frac{d\sigma\ (K_\pi, 0)}{dK_\pi\, d\Omega} \times 10^{30}$ (cm^2 Mev^{-1} ster^{-1}, carbon nucleus^{-1})

K_π(Mev)	π^+ mesons	π^- mesons	
25	4	.58	.05
35	5.2	.53	.06
54	13.3	.51	.05
67	12.3	.44	.06
72	12.3	.39	.04
113	(13?)	.22	.05

The data shows very surprising results which are in complete disagreement from the results one might expect from the relation:

$$\frac{\sigma_+}{\sigma_-} = \frac{A + Z}{A - Z} = \frac{3}{1}$$

Therefore there is reason to believe that the observed reaction of deuteron formation which has been shown to exist in free proton-proton collision may likewise occur during the process of meson production from carbon. Also the shift of the π^- spectrum peak towards the low meson energy, may be the result of a Coulomb barrier effect. It is expected that improvement of the data, and extension of the energy range of the investigation, will shed more light on the mechanism of the production process.

Pulse Height Experiment. Leroy Kerth, Stanley Leonard, J. Peterson.

The pulse height method for the identification of particles has been applied to the determination of the positive to negative production ratio, of π mesons from 345 Mev protons on carbon and lead at 0 degrees to the beam. The results are in disagreement with similar photographic emulsion data. At present, work is underway to resolve this disagreement and to extend this work to other elements, angles and other proton energies.

π^+ Meson Production Cross Section as a Function of Atomic Number. D. Hamlin, M. Jakobson, J. Merrit, and A. Schulz

Preliminary data on π^+ meson production cross section as a function of atomic number were recently published as UCRL-1433, and will shortly appear in the Physical Review. This data is for production at 0° and for 53 Mev π^+ mesons. It is planned to extend this to other energies and at various angles. The mesons were detected by the π - μ decay delayed coincidence detection scheme.

π^+ Production by Protons on Protons as a Function of Proton Energy. A. Schulz, D. Hamlin, M. Jakobson, J. Merrit.

Preliminary runs using the scattered external proton beam indicated that the

$\pi - \mu$ decay delayed coincidence detector gear would have to be modified on account of the high background. It was decided to completely modify the gear in other respects as well. A duplicate delayed coincidence chassis was built to economize on cyclotron time and to permit running background at the same time that data was being taken. The two crystal detection telescope was replaced by a three crystal telescope to further improve signal to noise ratio.

19. Synchrotron Studies

A. C. Helmholz

During the months of August, September, and October, the synchrotron was in operation, but mostly at a rather low level. Various and sundry difficulties have beset the operation. One of the main difficulties seems to be with the injector. One injector gave an excellent beam, comparable in intensity with those of last spring, but all others gave rather poor output.

During the period the experiment on the photodisintegration of the deuteron has made some real progress, and preliminary results will be reported at the December meeting of the American Physical Society in Berkeley. Measurements are made at photon energies of 200 and 250 Mev with a high pressure deuterium target at 2000 psi. and 77° K. Protons are differentiated from mesons and electrons by their ionization. Runs were made at angles of 30°, 45°, 60°, 75°, 90°, 105°, and 115°, the latter two angles being only for the 250 Mev photons. For both energies the maximum in the differential cross section in the center of mass system is definitely at angles smaller than 90° and is probabby at about 60° for 250 Mev, about 70°-75° for 200 Mev. The total cross sections are considerably larger than extrapolations of the present theories, which should be valid up to 150 Mev, would indicate. The total cross section at 250 Mev is 16.5×10^{-29} cm^2, at 200 Mev, 12.2×10^{-29} cm^2. Most of the necessary corrections, including nuclear abosrption in the absorber, have been applied, but the final results may be slightly different. Nevertheless this does indicate that the cross section is increasing with energy, and that it is quite large compared with what theories, not including mesonic effects, would predict.

In another attack on the problem, S. Kikuchi has been investigating the high energy protons in plates exposed by R. S. White and M. Jakobson to measure the meson yield from deuterium. By using grain density to determine that the particles are protons in the appropriate energy range, and by knowing the correlation between angle, proton and energy, and quantum energy, he also finds that the photodisintegration cross section increases at high energy, beginning approximately at the meson threshold. S. Kikuchi is making further analysis of more plates by counting proton endings, and so should be able to have numerical data in the near future.

It is perhaps also worthwhile to mention at this point that A. Wickersham in the Cloud Chamber Group is preparing to measure the photodisintegration cross section of deuterium also.

The other experiments approaching conclusions are those of R. Madey on π^{-} - p coincidences from D - γ, of R. Kenney on the Compton cross section of Be, in which experiment the pair cross section is also measured, and of W. Blocker on the Compton effect. These experiments have been going slowly because of the lack of intensity, but should be completed in the next quarter. As recorded in the Monthly Reports, runs have been made for other experiments, but results are not available from any of them.

20. Theoretical Studies

David L. Judd

A general study of the dependence of photonuclear cross sections on energy and atomic number has been undertaken. Qualitative agreement has been obtained between theory and experiment on some photonuclear effects, although both are only approximate as yet. This work is continuing.

Calculations have been begun on the influence of tensor forces between protons on scattering and on meson production.

An examination has been made of the various possibilities for explaining the very long lifetime of pi mesons against electron-neutrino decay.

The discrepancy between G. Chew's calculations and M. Stern's observations on the pickup process and the large-angle elastic p-d cross sections has been investigated. It has been found that for the pickup process in particular the Born approximation used by Chew is not valid. An improvement in this approximation is being attempted.

An attempt was made to apply the optical model of the nucleus to fit the experimental data on 42 Mev neutron cross sections to test its applicability in this energy range, but the results were not as good as had been hoped.

The shape of the high energy end of the meson spectrum from the photoproduction of negative pi mesons from deuterium yields information regarding spin flip processes. The calculated spectrum indicates that experimental detection is feasible, and experiments are being planned to attempt a determination of the probability of spin flip in this process.

A rough calculation of the diffraction scattering of 340 Mev protons from nuclei with variable nucleon density has provided a qualitative explanation of the observed washing out of diffraction pattern details in light nuclei. More exact computations are to be made.

An estimate has been made of the cross section for stripping a deuteron from a high energy He^3 nucleus.

Work is under way involving an extension of the Tomonaga approximation to field problems involving intermediate coupling. A study of the properties of non-linear spinor fields is also in progress.

The angular distribution of neutral photomesons from deuterium is being calculated under two assumptions (that the mesonic charges of the proton are the same or opposite in sign) with the hope that experimental results may serve to determine which is correct.

Work is continuing on an analysis of high energy n-d and p-d cross sections in terms of single nucleon cross sections, to study interference effects.

An attempt is under way to apply to nuclei a technique similar to that of the Fermi-Thomas statistical model of the atom, in order to compare the results with those from the shell model.

Experimental data on high energy photo-dissociation of nuclei is being examined; the angular distribution of the observed proton stars suggests the presence of a large free meson effect.

Work is in progress to determine to what extent the experimental data on scattering of protons from carbon can be used to determine the momentum distribution of nucleons in carbon nuclei.

Various high energy phenomena involving deuterons such as charge exchange scattering and photomeson production, are under study.

II ACCELERATOR OPERATION AND DEVELOPMENT

1. 184-inch Cyclotron Operation

J. Vale

Installation of a new 1250 kilowatt motor generator was completed last summer during the period that the cyclotron was shutdown for the cleaning of the lower magnet coil tank. This motor generator replaced the two smaller machines that has been in use since the cyclotron was put in operation. This step was taken because the smaller machines had to be overloaded for the proper excitation of the magnet and, consequently, trouble with the generator brushes was experienced.

After the new motor generator had been in operation for about a month, the generator bearings failed. No definite cause could be found for this failure but nevertheless considerable time was lost in replacing them. No more trouble has been experienced since their replacement.

Consequently, operating time during the month of August was only about 77 percent of the total crew time. The operating time for September and October was back to normal which is about 96 percent of thetotal crew time.

2. 60-inch Cyclotron Operation

G. Bernard Rossi

The operation of the 60-inch cyclotron during the quarterly period of August, September, October 1951, was as follows:

Alpha bombardments	392.6 hrs
Deuteron bombardments	462.1 hrs
Proton bombardments	178.6 hrs
C^{+6} bombardments	279.8 hrs
Development	100.2 hrs
OPERATION TOTAL	1413.3 hrs
Outage	269.3 hrs
TOTAL AVAILABLE TIME	1682.6 hrs
Shutdown	509.4 hrs
Holiday - Labor Day	16.0 hrs
Daylight Saving Time change	1.0 hrs
TOTAL TIME	2209.0 hrs

Much of the operations outage was necessary to replace ion source filaments. This outage has increased in recent months with the longer periods of C^{+6} ion work. The life of the filament from past history is certainly a function of the gas supplying the source. With deuterium, lives of 20 hours are common, with occasional expanses up to 50 hours; with helium, the lives are commonly 4-5 hours with hours considered a long period; with carbon dioxide gas, the lives vary from .9 - 1.2 hours.

Sometime ago the traditional three-turn horizontal coil of 80 mil tungsten was abondoned for a horizontal hairpin filament. When this switch was made, a steadier arc resulted; beam intensities were somewhat better, particularly near the end of the life; fabrication was speeded since stamping was practical; adjustment of filament with respect to source was more critical but also more fruitful. The short lives experienced with CO_2 gas make running very difficult because the adjustment period for maximizing the beam consumes a large fraction of the life span. Tantalum filaments were tried since the carbide has a melting point of 4150°C. compared to tungsten carbide which has only a 2857°C. melting point. This was abandoned because the tantalum under heat was soft, permitting the D.C. current to twist the filament due to "motor action" in the magnetic field.

Continued examination of the horizontal filament at various stages of wear showed marked correlation with beam intensities. It was noted that as the filament wore, its diameter decreased, thus localizing the heat and emission to a smaller area. By placing the horizontal filament vertically in the machine, the effective filament area exposed to the arc is greatly decreased but electron emission is not. This is because electrons boiling from the sides of the filament are drawn into the arc by the electric potentials and collimated by the magnetic field. The electron density is increased effectively without diminishing the mass of tungsten available for wear.

Two effects resulted from the vertical arrangement when using helium: (1) full value beams were recorded with new filaments which were equal in intensity to those of an aged horizontal filament and (2) filament life increases by a factor of 2 were realized, i.e., from 4-5 hours to 10 hours. With CO_2, similar effects were noted with lives consistently exceeding 1.7 hours. A hammerhead filament was then designed to provide more tungsten mass (Fig. 1). When used in two helium runs, this filament lasted for over 20 hours with beams comparable to the vertical hairpin filament over the entire life. With this type of filament, 30 milli-microamperes of C^{+6} has been measured at the 22-1/2 inch radius with energy exceeding 90 Mev.

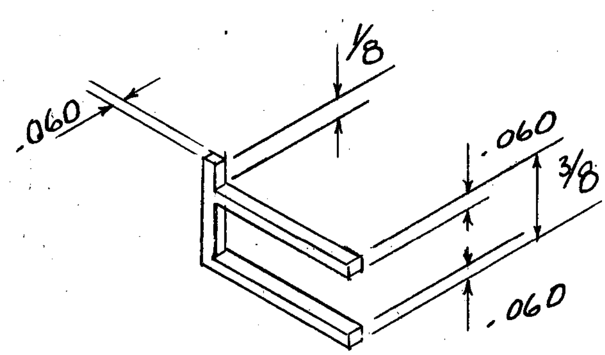

Fig. 1

Target Viewing Window:

The need for a method viewing the target area while the cyclotron is in operation has been apparent for some time. To fulfill this need, 1/2 inch plate glass cover plates were used for the 5 ft. x 4 ft. x 19 inch opening in the north water tank. Approximately 250 gallons of distilled water were added which had been treated with $ZnSO_4$ - $CuSO_4$ (10 p.p.m.) to a pH of 4.5. Lights which are controlled from the outside can be focused on the target area, permitting scrutiny of equipment during runs. The water provides adequate radiation protection.

3. Synchrotron Operation

George C. McFarland

During the month of August the synchrotron was run with a very usable beam intensity even though there was a continuous problem with a small leak. This leak was through a flaw in the quartz and could not be successfully stopped without disassembly of the magnet structure. Heavy applications of General Electric red glyptol applied warm to the leaking area reduced the leak rate enough to enable procurement of a good usable beam intensity.

September was a poor month of operation. Late in the first week, while making an entry into the quartz vacuum system, a sizeable piece of quartz section was broken. This piece was on a tubulation where a gasket and a blank plate were clamped to seal the system. It is possible that the break was on a flaw line. This could not be determined conclusively.

The magnet was disassembled and two new quartz vacuum sections were installed. Reassembly was completed three days after disassembly had started.

The rest of the month was exceedingly difficult. The betatron beam could be found at intervals but would disappear after a few hours. Elaborate monitoring of the magnet circuit and other components disclosed nothing amiss. Inspection in the vacuum chamber disclosed two pieces of rubber which were removed. Removal of the rubber pieces did not remedy the occasional appearance of the betatron beam and its subsequent disappearance.

It was noticed that the bean appeared without fail after an entry had been made into the vacuum system. As the pressure improved the beam began to disappear. Attempts to regain the beam by throttling the pumps so as to raise the pressure were not effective.

The vacuum donut was then sprayed on the inside with electrically conducting silver paint. The pressure remained high for a couple of weeks due to outgassing of the paint. During this time the betatron beam was readily obtainable and it showed no tendency to fade away.

During the second week in October, the beam intensity had been worked up so as to be barely usable for some experiments but not usable for those requiring a moderately high beam intensity. Only once, for a three day period in the third week of October, did the beam intensity reach nearly normal intensity. The machine was run 24 hours a day during this interval in order to catch up on the backlog of experiments. At the end of the three day period, the injector filament opened. The remainder of the month of October was lost to experimenters due to troubles with the injectors. Many injectors were tried and none were able to give a good beam intensity. Investigation of the injector problem is under way. A few new types were built and awaiting trial at the close of this report period.

Plans have been made and preliminary work has started on a high energy injection system. This device will produce electrons of 2 Mev or better with currents many times that which is needed to produce a high intensity beam.

The device to be employed is a traveling wave linear accelerator, similar to the one in successful operation at Stanford, built by Dr. R. Post and others. An inflector system using high voltage electrostatic plates will be used to guide the high energy electrons into the orbit.

4. Linear Accelerator and Van de Graaff Machines

With the exception of a small fraction of time devoted to machine research and minor repairs (i.e., replacing ion source parts and installing a new belt in the Van de Graaff generator), the linear accelerator was in constant operation during this entire quarter.

The time distribution for operation was as follows:

Running time	74.75 percent
Repair time	20.6 percent
Machine research	4.65 percent

5. Bevatron Development

W. M. Brobeck

Coil winding was within a few days of completion of the third quadrant at the end of the period. A bearing failure on the West Motor generator set during no load testing has been repaired and the machine has been given a check run. Plans are being made for testing the magnet power supply and magnet without pole pieces during the first part of next year. The magnet pole tip drawings and specifications have been approved by the AEC preparatory to requesting bids.

Arrangements have been made for fabrication of the vacuum tanks for the straight sections at Mare Island Navy Yard. Working drawings of the curved tank have been completed and drawings of the transition section between the straight and curved tanks are in progress.

The magnet air filter installation has been completed. One of the two permanent air compressors have been installed. Design of the motor-generator acoustic treatment is progressing.

Diversion of man power and space to classified work continues to prevent maintaining any schedule on Bevatron construction progress.

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