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Ernest O. Lawrence Radiation Laboratory

PHYSICS DIVISION SEMIANNUAL REPORT

May through October 1959

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[*] Preceding Semiannual Reports: UCRL-8936, UCRL-8545

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GENERAL PHYSICS RESEARCH

PHYSICS RESEARCH

Luis W. Alvarez in charge

LIQUID HYDROGEN BUBBLE CHAMBERS

Operation and Development

James Donald Gow

72-Inch Chamber

During May and June, the chamber engineering staff was occupied by the analysis of data accumulated during the successful month-long test run completed in April. Data from the test run indicated that pulse rates of more than 4 pulses per minute could not be sustained with adequate chamber sensitivity. The performance of the chamber was excellent in all other respects. Preliminary measurements indicated a spurious random curvature of the "no field" 3-Bev pion tracks exceeding 200-meter radius, which was the limit of accuracy of the measuring equipment available. This result is to be compared with an expected rms curvature of 700 meters due to multiple Coulomb scattering.

During May and June major effort went into the provision of a permanent liquid nitrogen system, modifications to the refrigerator compressor system, and preparation for the first research run. Cooldown began in mid-June and operation with an antiproton beam began on July 1. This run continued without serious interruption until its scheduled end on October 26. The chamber was maintained at liquid hydrogen temperature throughout the run except for a 2-day period of warming to 100°K required to remove nitrogen that had inadvertently been admitted to the refrigeration circuit. Expansion rates varying from 3 to 4 ppm were used.

During the running period a total of 180,000 photographs were taken and 30,000 antiproton interactions were observed. No major difficulties were encountered, but the long period of operation brought to light certain inadequacies in the purification system. These will be corrected prior to the next run.

15-Inch Chamber

The 15-inch chamber was not in operation during this period, but was installed in a K^+ beam at the Bevatron for use during November and December. The refrigerator, which had been under construction, was brought to completion and tested. The unit proved capable of removing 300 watts at a load temperature of 20°K, some 20% above design rating. Saving of liquid hydrogen cost will pay for the refrigerator during the projected K^+ run.

Optics and Data Reduction

Hugh Bradner

Approximately 20,000 events from the 10-inch and 15-inch hydrogen bubble chambers have been analyzed during the 6-month period. Four scanning machines and two measuring projectors were operated about 16 hours per day in order to get these results. This effort was sufficient to keep up with the most important physics in the film from the 10-inch and 15-inch chambers.

Experience in studying the antiproton interactions in the first experiment with the 72-inch hydrogen bubble chamber confirms our expectations that a much larger effort in scanning and measuring will be required to get the important physics out of the large chamber. Approximately 130,000 pictures have been scanned from this run, but only a very small fraction have been rescanned. Very few of the interesting events have been sketched, measured, and analyzed.

The data-reduction equipment and computing programs are continually reexamined and modified to improve reliability, and to reduce the data-reduction time. The main effort on equipment during the past half year has been in the illumination and film-transport systems of the big measuring projector, the electronic controls for the big measuring projector, and automatic film-advance mechanisms for the scanning machines and measuring projector.

Work has continued on the McCormick Rapid Reader. This will involve a whole new system of data handling, and will be reported in detail when it is operating.

Results of Experiments Performed with Hydrogen Chambers

Joseph J. Murray

The first major physics research experiment with the Laboratory's 72-inch liquid hydrogen bubble chamber was performed during this report period. One of the objectives of the experiment was the observation of antihyperon production via the reaction $\overline{p} + p \rightarrow \overline{Y}_1 + Y_2$. By use of the most advanced techniques of electromagnetic particle separation, a highly enriched antiproton beam was provided and some 25,000 antiproton interactions were photographed. When the chamber was operated at a momentum of 1.65 Bev/c (below threshold for antisigma production), nine cases of antilambda production were observed, implying a cross section of about 40 microbarns for the reaction $\overline{p} + p \rightarrow \overline{\Lambda} + \Lambda$. At a momentum of 2.05 Bev/c (above threshold for antisigma production), there has been observed, in addition to more antilambda production, one reaction of the type $p + p \rightarrow \overline{\Sigma}^0 + \Lambda$ — that is, production of a neutral antisigma hyperon, a particle theoretically expected to exist but hitherto unobserved. Thus far, however, in about 3000 antiproton interactions, no evidence has been found for the production of charged antisigma hyperons, indicating an upper limit of about 30 μb on the cross section for the reaction $\overline{p} + p \rightarrow \overline{\Sigma}^{\mp} + \Sigma^{\pm}$. A detailed study of the remaining antiproton interactions and scattering events is in progress.

Alvarez

Four other experiments using the 10-inch and 15-inch liquid hydrogen and liquid deuterium bubble chambers were commenced during previous report periods, namely,

(a) $\pi^- + p$ at 1.09 Bev/c;

(b) $K^- + p$ at rest and up to 400 Mev/c;

(c) $K^- + d$ at rest and up to 300 Mev/c;

(d) $K^- + p$ at 1.1 Mev/c.

Analysis of the data obtained in these experiments has continued with the following new results.

The final values for the associated-production cross sections were obtained in time for the Kiev meeting, and were presented there. For the most part these were in good agreement with cross sections previously published by others. The notable exception was the large value of 1.19 ± 0.14 mb found for the Λ-K^0 cross section at 1030 Mev/c incident pion momentum. This exceeds by a factor of two the value reported by the Columbia experimenters. The lambda production thus goes through a striking maximum at 1030 Mev/c. It is perhaps more than coincidental that this is exactly Σ^0 threshold, and is also exactly the location of the third resonance in π^--p total cross section. Conceivably a "cusp" effect is involved, but more data are needed to resolve the point.

By means of accurate measurement of the differential cross sections as a function of center-of-mass production angle in the reaction $\pi^- + p \rightarrow \Sigma^{\overset{-}{0}} + K^{\overset{+}{0}}$ at 1.09 Bev/c, it has been shown that the apparent violation of charge independence indicated by observations of Brown et al.[1] does not occur. It was demonstrated that the differential cross sections do indeed satisfy the well-known triangle inequality

$$\sqrt{2\sigma(\Sigma^0)} \geqslant \sqrt{\sigma(\Sigma^+)} + \sqrt{\sigma(\Sigma^-)}$$

required by charge independence to hold at all values of the production angle, and that the limiting case of equality is consistent with the results, implying zero relative phase between the amplitudes for the three processes

$$\pi^- + p \rightarrow \Sigma^- + K^+ ,$$
$$\pi^- + p \rightarrow \Sigma^0 + K^0 ,$$
and
$$\pi^+ + p \rightarrow \Sigma^+ + K^+ .$$

---

[1] Brown, Glaser, Meyer, Pool, VanderVelde, and Cronin, Phys. Rev. 107, 906 (1957).

Alvarez

It has been observed in the reaction $K^- + p \to \Sigma^+ + \pi^-$ at rest that the decay angular distribution of the Σ^+ in the rest frame of the Σ and with respect to the direction of motion of the Σ is isotropic. Together with the assumption that the K^- at rest in hydrogen (or deuterium) is absorbed from an S orbit--an assumption based on the recent theoretical arguments of Day, Snow, and Sucher[2]--this fact constitutes strong evidence that the spin of the Σ^+ is 1/2. A spin greater than 1/2 would necessarily be aligned so as to have a projection of not more than 1/2 along the direction of motion of the sigma and would therefore give rise to anisotropy in the decay angular distribution.

The analysis of $K^- - p$ interactions at 300 and 400 Mev/c has been completed. There were 170 elastic scatterings, 18 charge-exchange scatterings, and 104 cases of hyperon production. From the anisotropic angular distribution of the elastic scattering and the large total cross section it has been concluded that the p-wave interaction plays an important role at 400 Mev/c, a noteworthy fact in any theoretical analysis.

The decay angular distribution of the Λ in a new sample of about 200 reactions at rest of the type $K^- + d \to \pi^- + (p + \Sigma^0$ or $n + \Sigma^+) \to \pi^- + p + \Lambda$ has been analyzed. The results were consistent with no component of Λ polarization in the direction of motion of the Λ, leading to the conclusion (even when combined with an earlier, less certain result based on a smaller sample) that there is here *no* evidence for nonconservation of parity in strong interactions.

In the reaction $K^- + d \to \Sigma^- + n + \pi^+$ or $(\Sigma^- n) + \pi^+$, where $(\Sigma^- n)$ means the Σ^- and n are bound to form a hyperfragment, the analysis has been largely completed for the subclass in which the Σ^- or $(\Sigma^- n)$ stopped and was absorbed at rest, producing a Λ or $\Sigma^0 \to \Lambda + \gamma$ plus neutrons. It has been noted that if the hyperfragment is produced at all, it will be much more abundant in this subclass than in the whole class of $\Sigma^- - \pi^+$ events. The enhancement of the abundance is calculable within reasonable limits from a knowledge of the Σ^- lifetime. On the basis of only two out of 145 such events that could possibly, by the most lenient criteria, be interpreted as hyperfragments, it has been concluded that the branching ratio for $(\Sigma^- n)$ hyperfragment production in the K^--d reaction at rest is $< 1\%$. This fact may eventually take on special significance, since if the $(\Sigma^- n)$ is found to exist but to be forbidden here, and if one assumes with Day et al.[2] S-orbit capture, the K^- can be shown to be pseudoscalar on the basis of parity and angular-momentum selection rules.

Further details and reports of other work not mentioned here may be found in the following publications:

Leitner, Nordin, Rosenfeld, Solmitz, and Tripp, Search for Leptonic Decays of the Sigma, Phys. Rev. Lett. 3, 186 (1959).

H. Bradner and W. M. Isbell, Search for Dirac Monopoles, Phys. Rev. 114, 2, 603 (1959) Reprint (1959-171).

Frank S. Crawford, Jr., Linearly Biased Track Counting in Cross-Section Determinations, Rev. Sci. Instr. (to be published).

Leitner, Nordin, Rosenfeld, Solmitz, Tripp, Sigma Spin and Parity Conservation in $K^- + p \to \Sigma^+ + \pi^-$, Phys. Rev. Lett. 3, 238 (1959).

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[2] Day, Snow, and Sucher, Phys. Rev. Lett. 3, 61 (1959).

Eberhard, Good, and Ticho, A Separated 1.17-Bev/c K^--Meson Beam, Submitted to Rev. Sci. Instr.

Crawford, Douglass, Good, Kalbfleisch, Stevenson, and Ticho, Charge Independence in Hyperon Production, Phys. Rev. Lett. 3, 394 (1959).

Luis W. Alvarez, Hodoscope Design to Minimize Photomultiplier Use, Rev. Sci. Instr. (to be published.)

Frank S. Crawford, Jr. Absolute Differential Cross Section for Pion-Electron Scattering (Submitted to Phys. Rev.).

Luis W. Alvarez, in Procedings of the Ninth Annual Rochester Conference on High-Energy Physics, Kiev, 1959.

PHYSICS RESEARCH

Walter H. Barkas in charge

STRANGE-PARTICLE RESEARCH

Walter H. Barkas, Nripenda N. Biswas, Donald A. DeLise, John N. Dyer,
Harry H. Heckman, Conrad Mason, Norris Nickols,
Jack Patrick, and Frances M. Smith

Lifetime and Decay Modes of K⁻ Mesons

The analysis has been completed on 48 decaylike events in the 2B stack. Probability methods were used to calculate the relative populations of the various decay modes and of nuclear interactions that simulate decays. Independent estimates of upper and lower limits to the number of decays present were made. The percent branching ratios for the various decay modes measured are as follows: $K^-_{\mu 2}$, 56.5 ± 7.3 ; $K^-_{\mu 3}$, 9.5 ± 4.3; $K^-_{\pi 2}$, 26.3 ± 6.6; $K^-_{\pi 3}$, 2.8 ± 2.4; K^-_{e3}, 4.9 ± 3.2; τ^-, 0.0 ± 2.1. The K^--meson mean lifetime is $1.25^{+0.22}_{-0.17} \times 10^{-8}$ sec.

Search for Doubly Strange Heavy Meson

Stars in the 2B stack previously attributed to K^- mesons have been re-examined for evidence of double strangeness or visible energy release greater than the rest energy of the K^- meson. None has been found.

Charged Σ Hyperons

We now have recorded approximately 600 charged Σ hyperons in two emulsion stacks. Of these, 211 are decays into lightly ionizing secondaries, 147 are decays into protons, and 242 are Σ^- interactions. During this period our efforts have been concentrated on the decay into fast secondaries; of these, 71 leave the emulsion, 105 terminate in emulsion, and 35 have not been followed. The terminations include 62 pions at rest and 43 interactions in flight. No case is incompatible with the decay modes $\Sigma^\pm \rightarrow \pi^\pm + n$. Nineteen cases are $\Sigma^+ \rightarrow \pi^+ + n$ in which the decay occurs at rest and the pion comes to rest; these will yield an estimate of the Σ^+ mass which will be compared to the value obtained from the assumed decay $\Sigma^+ \rightarrow p + \pi^0$. From the above events we will obtain new estimates of the charged-hyperon lifetimes.

K^- Reactions with Protons

We have initiated a complete study of reactions of type

$$K^- + p \rightarrow \Sigma^{\pm} + \pi^{\pm} ,$$

where the K^- is absorbed at rest. Because of the large size of our emulsion stacks, we are able to follow the pion to rest in a number of cases. This yields information that has never been obtained before and improves the mass values for the Σ hyperon. These reactions, along with new data on Σ decays, overdetermine the Σ_0 masses and provide a check on the mass of the neutral pion from $\Sigma^+ \rightarrow p + \pi^0$.

The Λ-Hyperon Program

The study to determine the mass of the Λ hyperon, and consequently the Q value for its decay via the proton mode, is near completion. A total of 128 Λ-like events located in two emulsion stacks have been completely analyzed. Of this number, 116 were found to be Λ hyperons. All but one of the systematic errors entering the mass determination have been evaluated, and at present an investigation of this remaining error is under way.

Recently, a program has been initiated to derive the Λ-hyperon production spectrum from K^--meson reactions with emulsion nuclei. The theoretical aspects of this problem have been solved, yielding the necessary equations for the determination of this spectrum. An attempt is now being made to evaluate the spatial distribution of the K^- mesons in the emulsion stack, this being one of the important parameters in the above equations.

Nonmesonic Hyperfragments

We have examined some 60 hyperfragments that apparently are examples of nonmesonic decay. If the channels are assumed to be

$$\Lambda + p \rightarrow p + n + 175 \text{ Mev},$$

$$\Lambda + n \rightarrow n + n + 175 \text{ Mev},$$

then there is evidence that these two reactions are about equally probable. According to Ferrari and Fonda,[1] this indicates that there is little parity nonconservation in this process.

None of a sample of about 200 hyperfragments decayed by a leptonic mode. A Dalitz pair was associated with one hyperfragment; this is good evidence for the decay process $\Lambda \rightarrow n + \pi^0$.

---

[1] F. Ferrari and L. Fonda, Nuovo cimento 7, 320 (1958).

Barkas

High-Energy K$^-$-Meson Interactions in Emulsion

We have continued the study of interactions of 750-Mev K$^-$ mesons in emulsion nuclei[2] by investigating 189 additional events. These are interactions that were initially found in two plates by an area scan. Energy and charge distributions have been made for the charged pions and charged Σ hyperons emitted. These data have been added to the data obtained from the 102 previously reported events.

No evidence of the negative cascade particle, Ξ^-, has been found. We now have 18 cases of double pion production; 7 are accompanied by charged Σ hyperons and 1 with a hyperfragment. In all, there were 133 charged pions, 71 charged Σ hyperons, 16 hyperfragments, and 11 K$^-$ inelastic scatterings observed. One K$^-$ inelastic scattering was accompanied by an electron pair, demonstrating the production of an uncharged pion.

K$^-$-Meson Interactions with Single Nucleons in Complex Nuclei

In a preliminary work we completed a study of 180 two-prong stars in which one prong was a Σ hyperon and the other a π meson. We found that most of the energy required to remove the Σ-π system from the nucleus is taken from the π meson. The external energy spectrum of the Σ indicates some secondary interactions of the Σ inside the nucleus. Most of our events were peripheral interactions; when the Σ-π is formed deeper in the well, the absorption process $\Sigma + N \rightarrow \Lambda + N$ becomes considerable. Our data indicate the mechanism involved is explainable on a simple model.

In a continuation of the study of the mechanism of K$^-$-meson—nucleon interactions, we are now analyzing all one- and two-prong K$^-$-meson stars among 2400 found in the "A" stack. All events with one stable prong have been analyzed. Range measurements have been made on more than half the minimum-ionizing secondaries from one-prong events, and multiple-scattering and ionization measurements are being made on those that leave the stack. The ranges of all Σ hyperons from two-prong events have been measured.

Relativistic Region of Ionization in Nuclear Track Emulsions

A study of the ionization curve between the minimum and the plateau region has been initiated. The principal source of data for this investigation is a stack of nuclear track emulsion plates which was exposed to both 6.2-Bev protons and high-energy electrons. Grain densities are being determined by blob-counting methods. Additional points will be found by blob counting of K mesons and pions with high momenta (1.15 Bev/c). Ionization data from beam

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[2] Barkas, Biswas, DeLise, Dyer, Heckman, and Smith, Interactions of 1.15-Bev/c K$^-$ Mesons in Emulsion, Phys. Rev. Lett. 2, 466 (1959).

Barkas

pions, $K_{\mu 2}$ decay muons, and $K_{\pi 2}$ pions will also be used. The restricted energy-loss rate will be established for the plateau region by comparison of equal ionization points. The experiment is designed to check the present ionization curve. An important feature of these new measurements is that the emulsion temperature was maintained constant for formation of all the tracks, and the development was carried out before any fading could take place.

External Proton Beam

The external proton beam at the Bevatron was examined by the use of test plates. Beam profiles and a beam contour map were made by counting the number of protons in selected areas. Contours representing 200, 500, 1000, and 1200 $\times 10^3$ protons per cm^2 have been shown. The exposure was made with 2.4×10^8 circulating protons with the internal deflection magnet current of 985 amperes. An integrated count from the contour plot shows an efficiency of about 20% for beam extraction.

HEAVY-ION EXPERIMENTS

William Simon, Harry H. Heckman, and Betty L. Perkins

Measurements of equilibrium charge distributions of heavy ions in zapon, as described in the preceding report, have been completed for oxygen, nitrogen, carbon, and neon, and partial results are available for argon. Measurements are made in the energy range 2 to 10 Mev/nucleon, and charge states comprising as little as 10^{-5} part of the beam are measured. The errors are typically 2%, consisting primarily of counting statistics.

Plans are in progress to measure the energy and angular distributions of neutrons emerging from heavy-ion-induced reactions. A preliminary run has been made at the hilac to determine the neutron intensities. The design of a scattering chamber to accomplish these measurements is complete.

THEORETICAL GROUP

David L. Judd

PHYSICS OF THE NUCLEUS

Work on the deformation energy of a charged drop is continuing and the relations between the various families of equilibrium shapes of the drop are being clarified. Further evidence for a point of bifurcation in the conventional family of saddle-point shapes has been uncovered in the 1947 calculations of Frankel and Metropolis, and this provides a quantitative estimate of 0.73 for the critical value of the fissionability parameter x at which the bifurcation occurs. The question of the presence of stable elongated configurations of a drop for x in excess of the critical value is still undecided, although the semiquantitative IBM 650 calculations (work with Stanley Cohen) suggest their existence. The quantitative IBM 704 calculations are being continued (work with Victor Brady). Some further study of another point of bifurcation occurring in the neighborhood of $x = 0.4$ has been carried out. The associated family of equilibrium shapes determines the stability against asymmetry of saddle-point shapes for the fission of lighter elements, and is relevant in a discussion of the relation between fission and fragmentation reactions. (Wladylaw J. Swiatecki)

A calculation of the effect of collective nuclear interaction on nuclear binding energies is in its final stages. (Kenneth M. Watson and Yih Pwu)

The study of pair correlations in atomic nuclei, done with T. K. Fowler of Oak Ridge National Laboratory, was completed.[1] (Kenneth M. Watson)

In connection with the analysis of three-pronged events observed by Luis Muga (Chemistry) in photographic emulsions impregnated with Cf^{252} undergoing spontaneous fission, a study was made of the experimental data on range-energy relations of fission fragments and heavy ions in emulsions. (The latter from recent works of Barkas, Heckman, et al.) It was found that the available data were sufficiently extensive to permit a tentative interpolation between heavy ions and fission fragments, and such interpolation graphs were prepared for the ranges of nuclei with masses between 4 and 140 and energies between 10 and 140 Mev. A mechanical device incorporating these graphs was constructed for the determination of the unknown masses and energies from the angles and ranges in the three-pronged events observed by L. Muga.

(Wladyslaw J. Swiatecki)

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[1] Nuclear Phys., to be published (no further information provided).

Further analysis of range-energy relations of fission fragments (in collaboration with John Alexander (Chemistry) and Nathan Sugarman (Institute for Nuclear Studies, Chicago)) has shown a very close correlation between measurement of ranges as a function of fragment mass and time-of-flight measurements of fragment energies. The result has been to confirm the suspected energy deficiency of fragments in U and Pu fission in the rare cases of nearly symmetric division. The deficiency is about 20 Mev per fission and is confined to divisions in which the masses of the fragments do not differ by more than about 14 mass units. The hypothesis that the missing energy is associated with the long-range α particles observed in fission is being tested by Luis Muga (Chemistry). (Work with John Alexander, Chemistry) (Wladyslaw J. Swiatecki)

A simplified presentation of the theory of Watson, Heckrotte, and Glassgold on collective oscillations of nuclear matter has been submitted for publication.[2] A comparison with Landau's semiclassical theory is included in this report. (A. E. Glassgold)

NUCLEON SCATTERING THEORY

The data accumulated over the past year now make feasible an extension, to all energies, of the previous 310-Mev phase-shift analysis of the proton-proton scattering experiments. Although the neutron-proton data are not yet at this stage, a general program for the simultaneous analysis of all nucleon-nucleon data up to 400 Mev has been initiated and carried to the point where machine calculation on the proton-proton part is about to begin. In the energy dependence the parameterization is designed to be a continuation of the effective range theory, and also to take into account the fairly well known pole contributions due to the single meson exchange. It is planned to incorporate additional theoretical information or conjectures as they become available. (Henry Stapp)

The work on diffraction theory for high-energy nuclear scattering, reported in previous progress reports, has been submitted for publication.[3] By using this formalism, the first quantitative analysis of neutron-nucleus total and reaction cross sections at Bev energies was carried out. (Alfred E. Glassgold and Kenneth R. Greider)

The diffraction theory for high-energy scattering reported in UCRL-8900 is being extended to nucleon-nucleon and nucleon-antinucleon scattering. The preliminary results are that the nucleon-nucleon scattering amplitude is purely imaginary in the energy range from 1 or 2 Bev to 10 Bev, corresponding to a diffuse absorbing region of half-way radius equal to 0.8×10^{-13} cm. The nucleon-antinucleon scattering amplitude is essentially purely imaginary in the energy range from 0.5 to 2 Bev; it corresponds to a very diffuse absorbing obstacle of half-way radius equal to about 1.3×10^{-13} cm. (Alfred E. Glassgold and Kenneth R. Greider)

---

[2] A. E. Glassgold, Collective Oscillations of Infinite Fermion Systems (submitted to J. Nuclear Energy).

[3] K. R. Greider and A. E. Glassgold, Diffraction Theory for Very-High-Energy Scattering (submitted to Ann. Physics).

Judd

In the scattering of neutrons from nuclei in the energy range from 5 to 100 Mev, there are several families of resonances in the total cross sections. These resonances move to heavier nuclei as the energy is increased. Although this behavior is completely opposite to the single-particle resonances of Feshbach, Porter, and Weisskopf, they are still consistent with the optical model. According to the formulae of Fernbach, Serber, and Taylor, the total cross section is a maximum when $2k_1R = n\pi$, where k_1 is the change in the real part of the wave number, R is the nuclear radius, and n is an odd integer. By using known values of R and k_1 as a function of energy, the observed positions of the resonances can be explained in this simple way. The first "order" occurs near 100 Mev, the second near 25 Mev, etc. The single-particle resonances of Feshbach, Porter, and Weisskopf have still not been observed. (Alfred E. Glassgold and Ben R. Mottelson)

APPLICATIONS OF DISPERSION RELATIONS TO STRONG-COUPLING PHYSICS

The program of calculations based on the Mandelstam representation has yielded a number of important results. Two types of solution of the pion-pion integral equations have been found by Chew and Mandelstam, working with the Livermore 704 computer in collaboration with Noyes. The first type depends on one real parameter and is characterized by the dominance of the S wave. The second type is dominated by the P wave and appears to involve two real parameters. Numerical work on the first type is finished, but further machine calculations will be needed to thoroughly understand the second type, which seems more likely to be realized in nature.

Frazer and Fulco have completed their analysis of nucleon electromagnetic structure in terms of a pion-pion interaction.[4] They find that all the observed isotopic vector properties can be understood if there is a fairly sharp P-wave π-π resonance at a total energy between 3 and 4 times the pion rest energy. Kim is calculating the consequences of such a resonance for a Bevatron experiment planned by the Segrè-Chamberlain group for next February.

Calculations by H. Wong of the process $\gamma + \pi \leftrightarrow 2\pi$ are nearly complete. These results are being used in turn by Ball for the more complicated but experimentally more accessible process $\gamma + N \to \pi + N$. Ball is concentrating for the present on the behavior of the photopion cross section near threshold, and some results are already available.

The nucleon-nucleon interaction is being attacked from two directions. Cziffra is calculating the one- and two-pion exchange contributions to higher angular momenta, while Wong and Noyes are concentrating on the S waves. In both cases the one-pion effects are well in hand,[5] and a large part of the highly complex two-pion calculation completed. The technique for incorporating Coulomb effects into proton-proton scattering has also been worked out by Wong and Noyes.

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[4] William R. Frazer and Jose R. Fulco, Partial-Wave Dispersion Relations for the Process $\pi + \pi \to N + \overline{N}$, Phys. Rev. (to be published); Effect of a Pion-Pion Scattering Resonance on Nucleon Structure (submitted to Phys. Rev.).

[5] H. Pierre Noyes and David Y. Wong, A Modification of the Effective-Range Formula for Nucleon-Nucleon Scattering, Phys. Rev. Letters 3, 191 (1959).

Pusterla and Ferrari, in partial collaboration with Nauenberg, have been studying the consequences of partial-wave dispersion relations for the K-N, π-Σ, π-Λ system. They have established the connection with the empirical effective-range formulas of Dalitz and laid the foundation for a systematic improvement of these formulas. (Geoffrey F. Chew)

An investigation of the relativistic π-Y dispersion relations was completed with Richard Capps (Cornell preprint), and will be submitted for publication.[6] (Michael Nauenberg)

NUCLEON-ANTINUCLEON ANNIHILATION

The annihilation of antiprotons in "protonium" has been reconsidered by Desai in the light of the Day-Snow-Sucher mechanism for nuclear capture via the Stark effect. It is found that, just as for K^- mesons, the Stark mixing leads to almost certain capture via S states at high principal quantum numbers. (Geoffrey F. Chew)

The probabilities for production of different kinds of K-meson pairs in the annihilation of antiprotons in isotopic spin-zero nuclei, such as carbon, have been computed in terms of three amplitudes for the possible isotopic spin states. These lead to expressions for the probabilities of detecting a particular kind of K meson which satisfy certain inequalities such as

$$P(K^+, \bar{K}^0) + P(K^-, K^0) \leqslant 2\left[P(K^0, \bar{K}^0) + P(K^+, K^-)\right] ,$$

which may be tested by the antiproton experiments in a propane bubble chamber. (Gerald Feinberg)

In connection with experiments on angular correlations of multiply produced mesons an attempt has been made to calculate the effects by including in the Fermi statistical model phenomenological correlations among the random variables. The results turned out to be too ambiguous for physical interpretation, and it was concluded that the effects are intrinsic rather than purely statistical. (Maurice Neuman)

The question was considered of what one may hope to learn from nucleon-antinucleon interactions, keeping in mind that the bulk of the encountered phenomena are highly complex (production of many particles per event). It was noted that such phenomena provide tests of the validity of parity conservation and of charge-conjugation invariance in energy regions not sensitively explored hitherto. It was further noted that invariance arguments are of great help in the study of the polarization and the decay of antihyperons; and that the comparison of $\bar{\Lambda}$ to Λ decay is of interest for a study of time-reversal invariance.[7] (A. Pais)

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[6] Sulamith Goldhaber, T. F. Hoang, Theodore E. Kalogeropolis, and Wilson M. Powell, Phys. Rev. Letters 3, 181 (1959).

[7] A. Pais, Notes on Antibaryon Interactions, Phys. Rev. Letters 3, 242 (1959).

Judd

Work is in progress on a possible theoretical interpretation of correlation effects in $\bar{p}$-p annihilation observed recently.[8] It appears promising to view these effects as due to Bose-Einstein correlations between pions of like charge. Numerical evaluations are in progress and seem to reveal a sensitive dependence of the effects on the radius characteristic of the spatial size of the annihilation region. (A. Pais)

The determination of the effect of final-state interactions on the production of antinucleons by pions is nearing completion. The procedure is to take the basic matrix elements from perturbation theory, but to put in the correct asymptotic wave functions for the two nucleons in the final state. The cross sections have been obtained in closed form and are currently being tabulated on the IBM 650 computer. (Owen Eldridge)

A study is being made of the angular correlations found between pions emitted in nucleon-antinucleon annihilation. The basic question is whether the observed correlation effects, which are different for (π^+, π^-) and $(\pi^\pm, \pi^\pm)$, are due to final-state interactions or merely due to asymmetries in the matrix elements for the processes. Two independent procedures are being followed. One is based on a model akin to that of Fermi. The other is an evaluation of correlation effects using lowest-order perturbation theory. This should be legitimate as long as one is merely studying effects that do not involve final-state interactions. (Ernest Abers, Michel Nicola, and Joseph V. Lepore)

FURTHER STUDIES ON THE THEORY OF STRONG INTERACTIONS

The consequences of noninvariance under C, P, or T of reactions in which for each outgoing particle there is a corresponding outgoing antiparticle or incoming particle, or in which for each incoming particle there is a corresponding incoming antiparticle or outgoing particle, are obtained by examination of the Wolfenstein (proper spin) scattering matrix. Simply describable restrictions on the Wolfenstein matrix are obtained for cases of arbitrary numbers of bosons and fermions. The general treatment is specialized to the case of the reaction $p + \bar{p} \rightarrow \Lambda + \bar{\Lambda}$. Relationships among the observables imposed by T, C, and P invariances which are not obtained by the elementary methods are deduced. Also, for this reaction, the explicit parametric expressions in terms of the six complex scalar amplitudes are obtained for the twenty-four independent scalar observables at each production angle. (Henry Stapp)

An analysis of the $\bar{K}$-p data reported at the Kiev Conference was made with Ulrich Kruze to determine the S-wave $\bar{K}$-N scattering amplitudes.[9] (Michael Nauenberg)

The properties to be expected of general systems of baryons under various strong-coupling hypotheses are being studied. In particular the possibility of forming and the properties to be expected of Ξ^- hyperfragments and bound dihyperons (e.g., a bound Λ-Σ system) are being investigated. (C. Gerald Gardner)

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[8] Goldhaber et al., Phys. Rev. Letters 3, 181 (1959))

[9] Ulrich Kruze and Michael Nauenberg, S-Wave $\bar{K}$-N Scattering Amplitudes, UCRL-8888, Sept. 1959.

The dependence on atomic number of the yield of neutral photomesons from complex nuclei has been measured at 45, 90, and 135 deg. An attempt is being made to explain those measurements in terms of the direct-interaction model. It is not entirely clear at this point that the model is applicable, since the energy of the mesons may be too low. (Robert Traxler)

WEAK INTERACTIONS

The decay of the π^0 is being studied in an effort to determine its form factor from the observation of the angular distribution of internal pairs. Under the assumptions of relativistic invariance and pseudoscalar π^0, the process

$$\pi^0 \rightarrow e^+ + e^- + \gamma \qquad (1)$$

was studied in detail by using quantum electrodynamics in addition to the above assumptions. An angular distribution for the pairs was obtained. The radiative corrections are now being made. The process

$$\pi^0 \rightarrow e^+ + e^- \qquad (2)$$

is being studied for its contribution to (1). This contribution arises experimentally because of the bremsstrahlung of one of the electrons and also because (1) and (2) appear identical for γ energies below a certain limit. These preliminary studies indicate that the determination of the π^0 form factor by this method is not possible with present experimental accuracy. (Michael M. Austin)

A paper has been prepared on radiative pion decay.[10] (Sidney Bludman and James Young)

It has been shown that the introduction of an arbitrary "off-diagonal mass" type of interaction, or an "off-diagonal momentum" type of interaction between μ meson and electron does not lead to any real transition between μ and e, because it is possible to transform the total Lagrangian to a form in which no "off-diagonal" terms exist. (Gerald Feinberg and Steven Weinberg)

Calculations are in progress on the nuclear absorption of muons in PμP, Pμd, and dμd molecular ions, using wave functions obtained from the calculations of Cohen, Judd, and Riddell.[11] These calculations will permit use of a measurement of molecular ion absorption rates to obtain the μ-absorption rates and hyperfine effects in atomic hydrogen and deuterium. (Steven Weinberg)

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[10] Sidney A. Bludman and James A. Young, Radiative Pion·Decay into Electrons (submitted to Phys. Rev.)

[11] Stanley Cohen, David L. Judd, and Robert J. Riddell, Jr., Mu-Mesonic Molecules. I. The Three-Body Problem; II. Molecular-Ion Formation and Nuclear Catalysis (submitted to Physical Review); III. Tabulation of Potential Functions and Dynamic Correction Terms for the Hydrogen Molecular Ion (unpublished).

Judd

A paper has been prepared on the relations and transformations between muons and electrons.[12] It was shown that under certain reasonable physical requirements (renormalizability, no ghost states, etc.) it is impossible to write a Lagrangian that can lead to a strong or electromagnetic decay of muons into electrons. It is possible to rewrite the conventional theory of muons and electrons in a form that possesses complete μ-e symmetry, except for weak interactions. (Steven Weinberg, with Gerald Feinberg of Columbia University)

A theoretical study has been made of the weak decay processes $\Sigma^{\pm} \rightarrow \Lambda^0 + e + \nu$. Measurement of the rates and spectra of these processes can give direct information about (a) the correctness of the Feynman-Gell-Mann conserved-current theory; (b) the correctness of the Fermi-interaction picture of weak interactions; (c) the lifetime of the Σ^0 particle. This work will be published in the Physical Review. (Steven Weinberg)

Calculations are in progress on the possibility of testing the absence of $\Delta I = 3/2$ terms in τ and τ' decay by studying the distribution of events in the Dalitz triangle. (Steven Weinberg)

Research efforts in collaboration with Dr. Victor Emery have been devoted to a study of energy gaps in liquid He^3 and nuclear matter. This is an outgrowth of previous work,[13] and has taken two main directions: First, we are using the high-speed computing facilities at the Laboratory to calculate the energy gap in infinite nuclear matter. A computer program has been written and is in the stage of being "debugged." Analytic work is being done to understand the factors influencing the size of the energy gap. Second, we have shown by extending methods previously developed,[14] and following a suggestion of Mottelson, that liquid He^3 is superfluid at sufficiently low temperatures. Attempts are being made to estimate the transition temperature semi-analytically (using digital computation to evaluate certain integrals), and preliminary work indicates that the transition temperature is extremely low. Studies are in progress to determine the most feasible way to compute the transition temperature accurately. (Andrew M. Sessler)

A paper concerning the effects of the Pauli principle for electron-atom scattering was written in collaboration with Lippmann and Mittleman.[15] A second paper, applying the method of the earlier paper, has just been completed.[16] Further work is in progress.

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[12] Feinberg, Kabir, and Weinberg, Phys. Rev. Letters 3, 527 (1959)

[13] Cooper, Mills, and Sessler, Phys. Rev. 114, 1377 (1959); Mills, Sessler, Moszkowski, and Shankland, Phys. Rev. Letters 3, 381 (1959).

[14] Victor Emery, Nuclear Phys. 12, 69 (1959).

[15] Bernand A. Lippmann, Marvin Mittleman, and Kenneth M. Watson, The Scattering of Electrons by Neutral Atoms (submitted to Phys. Rev.).

[16] Marvin H. Mittleman and Kenneth M. Watson, Effects of the Pauli Principle on the Scattering of Electrons by Atoms at High Energies (submitted to Ann. Rev. Nuclear Sci.).

Judd

Mr. Robert Traxler has almost completed an analysis of nuclear binding effects for photopion production. He is now applying the calculation to a study of experiments recently done at Lawrence Radiation Laboratory (Kenneth M. Watson)

The statistical mechanics of Bogoliubov's low-density theory of liquid helium has been worked out. New results obtained are the temperature-dependent pair-correlation function and the moment of inertia of a rotating bucket of liquid helium. An attempt to extend the low-density theory by using earlier results[17] failed in first order. More general canonical transformations and Green's-function techniques are now being considered. (Alfred E. Glassgold, Allan Kaufman, and Kenneth M. Watson)

The conditions for the existence of an energy gap in the theory of Bardeen, Cooper, and Schieffer for infinite fermion systems have not yet been investigated in detail. For a monotonic potential, it is easy to show that the requirement is that the potential be attractive and that the essential function is the Born-approximation phase shift. To investigate more complicated forces, sums of products of factorable potentials have been considered. The condition appears to be that the scattering phase shift to positive, which is the generalization of the simple condition discussed above. (Alfred E. Glassgold and Ben R. Mottelson)

Field Theory

A study is being made of the possibility that subtractions are required in the dispersion relations for the propagators of elementary particles. In such a case the conditions on the high-energy behavior of vertex functions, etc., become extremely stringest. Corresponding results can also be obtained for the forward scattering of neutral particles. (Steven Weinberg)

A paper on the commutation relations of nonrelativistic quantum mechanics has been written.[18] This shows the relation between the commutation relations of the theory and the representation of translations, Galilean transformations, and rotations of the physical coordinate system by unitary transformations acting on the space of state vectors. The intimate connection between the commutation relations and the probability hypothesis of quantum mechanics is stressed. (Joseph V. Lepore)

The theory of a charged vector particle is being studied for renormalizability conditions with the idea of application to the theory of weak interactions. (James A. Young)

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[17] Glassgold, Heckrotte, and Watson, Linked-Diagram Expansions for Quantum Statistical Mechanics, Phys. Rev. 115, 1374 (1959).

[18] Joseph V. Lepore, The Commutation Relations of Quantum Mechanics (to be submitted for publication).

Consideration has been given to what restrictions would be imposed on the possible asymmetries in nature by postulates of impossibility of experimental definition of coordinate systems with respect specifically to (a) screw sense, (b) time sense, and (c) sign of charge; it is generally known that although P, C, and T invariance guarantee the above, they are not required by the above. The result is either of two possibilities, one of which is ruled out by observed parity violations, the other being TCP invariance. Further, to rule out enough other asymmetries to get T and CP invariance separately, one need only postulate that choice of screw sense and choice of time sense be independent (no orientation of 4-space as a whole). This discussion is embodied in a recent paper.[19]

An investigation of the covariant dispersion relation of Mandelstam is currently in progress. (Maurice Neuman)

The gage properties of propagators in quantum electrodynamics have been investigated. The relation between the propagators in various gages has been found. Among the gages studied are the Coulomb gage and the relativistic gages (Feynman, Landau, and Yennie). From the transformation formula for the electron propagator a formula for the transformation of the wave-function renormalization constant Z_2 has been derived. This result, obtained in collaboration with Kenneth Johnson, has been used to study the infrared structure of the electron propagator. Two papers have been prepared.[20] (Bruno Zumino)

Various Accelerator Studies

Coherent radiation in high-current accelerators is being investigated in cooperation with Andrew Sessler. Some details are lacking, but the general conclusion is that this effect is not an important one for currents of the order of amperes. If the walls of the vacuum tank are of conducting material the losses are of two types. The first is a simple Joule heating of the walls caused by the passage of image currents. The second mechanism is the possible resonance of the beam with the characteristic electromagnetic modes of the vacuum tank. Such resonances are possible only for relativistic velocities. Numerical results depend on the major radius of the machine, cross-sectional dimensions of the vacuum tank, and distribution of the particles in azimuth . The second case examined is a beam inside a vacuum tank that is nonconducting. As an approximation to the actual case, the beam was considered to be circulating in free space. Results of this calculation are several orders of magnitude higher than for the former case, but still nothing to worry about. On the other hand, the effects of a high-current beam on the accelerating rf cavity appear to be a problem. The bunched beam interacts with the cavity very much like the bunched electrons in a klystron. Calculations of this effect are far from complete, but indications are that it will limit the total charge possible in the accelerator as well as creating difficulties in driving the cavity. (V. K. Neil)

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[19] Elihu Lubkin, TCP as a Space Reflection (letter to the Editor), Nuovo cimento (to be published).

[20] Bruno Zumino and Kenneth Johnson, The Gage Dependence of the Wave-Function Renormalization Constant in Quantum Electrodynamics (submitted to Phys. Rev. Letters); Bruno Zumino, The Gage Properties of Propagators in Quantum Electrodynamics (submitted to J. Math. and Phys.).

A parametric study at 200, 100, and 70 Mc has been made for a Bevatron injection system utilizing a quadrupole-focused linac. The bore sizes, magnetic quadrupole gradients, energy spreads, debunching distances, and polarity configurations have been given for four energy ranges: 0.50 to 10 Mev, 0.75 to 10 Mev, 0.50 to 15 Mev, and 0.75 to 15 Mev. The magnetic quadrupole requirements are relaxed appreciably as one goes to the lower frequencies, but the drift distances necessary for debunching become excessively long. This work has been set forth in an internal report.[21] (John Hiskes)

An investigation has been made of multiturn linac injection into the electron synchrotron. The acceptance of the beam with respect to both the synchrotron and the betatron oscillations has been examined by using empirical data available from the rf linac. This study has not been exhaustive, but has been carried sufficiently far to indicate that there is small probability of increasing the output beam current using linac injection over the present betatron operation. A separate report on this work is to be prepared. This work was done in collaboration with Kenneth C. Crebbin of the synchrotron group. (John Hiskes)

A FORTRAN II code is being written which will accept as input the experimentally measured values of the magnetic field of the Bevatron, in the form in which they presently exist, and will produce by interpolation a set of field values in a form that can be used as input to the Oak Ridge general orbit code No. 1821. (C. Gerald Gardner)

A problem relating to the transmission of electrostatic deflectors in cyclotrons has been solved analytically. Numerical values for physically relevant parameters are currently being computed. (Maurice Neuman)

The present easy availability of an IBM 704 computer at the Laboratory suggests that computational procedures for Bevatron orbits should be revised. As a first step in this direction, two recently completed Oak Ridge cyclotron orbit codes are being suitably modified. The first code (No. 1482) will trace equilibrium orbits at a series of momentum values and calculate the focusing frequencies, along with other useful data. The second code (No. 1821) will trace arbitrary orbits, for studying extraction, nonlinear effects, and other phenomena. The magnetic field is specified by values stored on magnetic tape, using a uniform (r, θ) mesh. The variables r and θ are polar coordinates centered at the machine center, and the fields are to be obtained by interpolation (elsewhere described) from the available data. It is hoped to obtain tapes both for high field and low field, the former for extraction studies, and the latter for injection. (T. A. Welton)

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[21] John Hiskes, Injection System Parameters as a Function of Frequency, Bev-424, May 12, 1959.

Judd

Work is being done continuing the studies of Dr. Lloyd Smith on the Bevatron beam-extraction program. A study has been started of the possible use of two deflecting magnets following the energy-loss target, rather than one, as is used in the present experiment. (Alper Garren)

88-INCH CYCLOTRON DESIGN STUDIES

Alper Garren

1. Analysis of Vertical and Radial Stability of Magnetic Field as Measured in 1/5-Scale Model

Work last winter with Dr. Lloyd Smith produced rather accurate analytic expressions for axial and radial betatron frequencies and the nonlinear radial instability in terms of the Fourier coefficients describing the field, and their radial derivatives. With the help of Mr. Robert J. Harvey, IBM-650 codes were written to obtain these coefficients and their derivatives from measurements made on a polar grid, which may be used as input for a code written by Mrs. Ardith Kenney for calculating with the above analytic formulas, or into the MURA IBM-704 orbit codes for calculating detailed orbits and betatron frequencies. Reasonable agreement was obtained between the analytic formulas and frequencies calculated by these codes and the Oak Ridge code described below.

Meanwhile a much faster code (No. 1482) for calculating equilibrium orbits and betatron frequencies was prepared at Oak Ridge, which uses the field measurements on a grid rather than the Fourier representation thereof. With the help of Mr. Douglas R. Brainard, an IBM-704 code (DORO) was then written here to process the model measurements in a form suitable for use in No. 1482. The most important feature of this code is that it calculates the corrections in the radial profile of the field required for isochronism and, if desired, alters the measurements accordingly before inserting them into No. 1482.

By using DORO and No. 1482 a large volume of model magnet measurements has been processed, which indicate that deuterons up to 60 Mev, protons up to 50 Mev, and various heavy particles will be stable during acceleration.

2. Obtaining an Isochronous Radial Field Profile with Trim Coils

Since this machine is to be of constant frequency and variable energy, one must adjust the radial field profile differently for each particle and energy. Calculations of the required corrections to the measured data are obtained by DORO. These corrections are to be achieved by 17 concentric trimming coils on the magnet pole faces. A method has been devised, using the theory of linear programming, to determine the particular combination of currents in the coils (subject to specified current limits) that minimizes the largest phase gain or lag the particle will experience. To apply this method Mrs. Ardith Kenney has written a code for the IBM-650 to prepare input for a RAND Corp. IBM-704 linear programming code which calculates the required currents. Several of the model-magnet measurements have been processed, showing the feasibility of the method and helping to determine the required coil power-supply configuration.

3. Beam Extraction

Alper Garren, Lloyd Smith, and David Judd

All thinking so far has been devoted to electrostatic deflectors. To determine their effect we calculated deflected orbits analytically and by computer. For a single deflector the electric field needed for 60-Mev deuterons is unpleasantly high, about 160 kv cm. A more complex scheme, using three deflectors in series--one pushing inwards--has been investigated and shows promise. Other possibilities remain to be studied, such as extraction beyond the nominal extraction radius.

An important aspect of electrostatic beam extraction is the question of deflector acceptance, which has been studied by Dr. Lloyd Smith, Dr. David Judd, and me. Most results of the analysis may be conveniently obtained by use of a graphical method. The important variables involved are the channel width and length, septum thickness, electric field strength, and frequency and amplitude of radial oscillations. Subsequently Dr. Maurice Neuman has made an equivalent analytic formulation with a view to possible solution by computer.

Since electrostatic extraction for the highest-energy particles looks difficult, we will study regenerative techniques as possible alternatives.

4. Depolarization

Since some hope exists for developing ion sources of polarized particles, a calculation has been made of the depolarization effect in spiral-ridge cyclotrons. One finds that in general the spin both precesses and nutates about the vertical direction. Dangerous nutation for particles originally polarized vertically can occur when integral relations exist between vertical and radial oscillation frequencies, the number of sectors in the machine, and the anomalous magnetic moment. For protons it appears that serious depolarization will not occur during the number of revolutions needed for acceleration.

MATHEMATICIANS

Data Reduction for Hydrogen Bubble Chamber Group

The computer program LSI was modified to perform double precision arithmetic. This program, written for the IBM 650, will solve an overdetermined system of linear equations by the method of least squares.

A series of three programs--FID 1, FID 2, FID 3--was written to calculate optical constants for the 15-inch hydrogen bubble chamber. These programs determine parameters of a linear transformation of points from the film plane to the plane of the fiducial marks in the 15-inch chamber.

Several 704 bookkeeping programs were written. One of these, SKELM 72, takes Franckenstein data from magnetic tape and (a) makes an on-line listing of the serial numbers of all events on the magnetic tape, (b) makes an off-line listing of the indicative information on each event. SKELM 72 was written for data from the 72-inch chamber. There is also a version of this program for data from the 15-inch chamber. Another of the bookkeeping routines written orders data on a magnetic tape according to event serial number and event type.

Two tape-handling routines were written to merge any number of data tapes (of a given form) onto one tape.

Event-type subroutines, necessary to run data through the space-reconstruction program PANG, were written for the cascade and deuterium experiments.

Two output subroutines, ART and JIM, were written for the kinematics program KICK. These routines reproduce KICK-calculated quantities in a readable output form.

The following programs are currently being written:

A 704 program that will make up wiring diagrams for the McCormick reader.

A filter program that will take output from the McCormick reader and reconstruct the film tracks.

A 650 program to do bipole focusing of charged particles. (Daphne Innes, Russell Johnson, Barbara Levine, Alice McMullen, S. Singer, J. Young and Robert Harvey, for the Hydrogen Bubble Chamber Group)

Other Activities of the Mathematicians

An IBM 650 program is being written, using a least-squares fit, for computation of experimental data obtained from a colorimetric reaction. The reaction involved is the reduction of ceric sulfate in the presence of arsenious oxide as catalyzed by iodide. By this method it is possible to quantitate minute amounts of iodine present in human and animal sera. These measures serve in the evaluation of thyroid gland activity. The computer program will replace a hand-plotting method presently used. (Virginia Richardson for Gilles La Roche)

An IBM 650 code to calculate frequency distributions for synchroton fission runs has just been completed. The program accepts input data on pulse heights, pulse times, and validity of the event, and computes distributions of number of pulses per event, prompt-particle and neutron pulse-height distributions per run, and the distribution of prompt and neutron times per run. Programming is under way to obtain comparable information for background and target runs. (Seymour Singer for Burns MacDonald)

Given the projected lengths and angles of a three-pronged event, an IBM 650 program was written to compute the original path lengths and the angles between them. The program is also able to compute the original path lengths of any further scattering from either of the three prongs, given the projected lengths. (Claudette Evenson for Luis Muga)

An IBM 650 program is in progress which will compute

$$\eta_0 = \frac{\int_{\theta_1 - \pi}^{\theta_1 + \pi} \epsilon\left[J(\psi)\right])\, J(\psi)\, d\psi}{\int_{\theta_1 - \pi}^{\theta_1 + \pi} \epsilon\left[J_0(\psi)\right])\, \left[J_0(\psi) + K(\psi)\right] d\psi},$$

where the functions are defined as

$$\epsilon(x) = \begin{cases} 1 & \text{for } x > 0, \\ 0 & \text{for } x \leqslant 0 \quad \text{for any function } x, \end{cases}$$

$$J(\psi) = \begin{cases} j_2 & \text{for } 0 \leqslant j_2 < j_\sigma, \\ j_\sigma & \text{for } 0 < j_\sigma < j_2, \\ 0 & \text{for either } j_2 \leqslant 0 \text{ or } j_\sigma \leqslant 0, \end{cases}$$

where j_2 and j_σ are defined by six different functions over the range of integration;

$$J_0(\psi) = q_0 - H(\psi, \alpha) + \sin\psi - \cos(\psi - \theta_1),$$

$$K(\psi) = (\theta_1 - \theta_0)\left[(k/2) - \sin(\psi - \theta_1) + \epsilon(\psi - \theta_1)\, \frac{\sin^2(\psi - \theta_1)}{k}\right],$$

where α, θ_1, θ_0, k, q, q_0, σ are input parameters. (Claudette Evenson for Maurice Neuman)

An IBM 650 subrouting, DFQP, was written to solve ordinary differential equations of third order or less where the solution is expressible as a power series near initial point. The form of the output is optional. (Jonathan Young for Kent Curtis)

An IBM 650 program, HONE, was written to aid in the determination of K and π momentum spectra in four-, five-, and six- particle reactions. (Jonathan Young for Peter Hoang)

Judd

An IBM 650 program was written which calculates distribution functions (two parameters), where the per cent of radiation activity from particles scattered into each of four (or five) counters is known. The activity in the target material is also computed. The program assumes a constant range for all particles, with

Range = k x velocity or Range = $k_0 + k_1$ + velocity (k_0, k_1, k known).
(Edwin Towster for John Alexander)

A series of IBM 650 programs for the analysis of pion photoproduction in deuterium has been completed. These programs, the PEA SOUP series, use the equations of conservation of energy and momentum as constraints to adjust four measured coordinates of the three-prong event, the three stereo-axis coordinates of the prong end points, and the other coordinate perpendicular to the beam direction for the event origin. The procedure of adjustment is like the IBM 650 KICK program or the IBM 704 GUTS routine. (Richard Mitchell for William Swanson)

A program to calculate laboratory-system momenta and angles for each final-state particle from the reaction $\gamma + d \rightarrow \pi^- + 2p$ has been written. (M. Simmons for W. Swanson)

A Monte Carlo program to compute neutron-energy spectra and angular distributions of heavy-nuclei recoils has been written. Basic variables are the incident particles, their energy, and the target nuclei. (W. H. Hutchinson for Bernard Harvey and Jack Morton)

IBM 650 programs have been written to compute the quantity

$p^n = (\ell_1, \ldots \ell_n, E_0^T, R_F)$ for various numbers and combinations of π and K mesons. (M. Simmons for Roy Cook)

Numerous IBM 650 programs have been written to calculate phase-space integrals for pion-pion interactions for four, five, and six particles, for use in connection with experiments in the propane bubble chamber. (M. Simmons for G. Goldhaber)

A program has been written for the IBM 650 which evaluates numerically an integral arising from the classical treatment of the Coulomb excitation process. The integral evaluated is

$$\left|C\right|^2 = \frac{1}{\tau} \int_{-\infty}^{\infty} \left|b\ (t)\right|^2 dt,$$

where

$$b(t) = e^{-t/2\tau} \int_{-\infty}^{t} \ell^{s/2\tau} \ell^{iws} \frac{\left[X_b(s) + i\mathcal{J} X_b(s)\right]^{\mu}}{r_b(s)^{\lambda + \mu + 1}} \cdot d\ell .$$

It is integrated by using Simpson's rule, and allows for automatically taking a finer step length at any point where the error is too large.

Judd

The input parameters are $\sigma = 1/2\ \tau\omega$; $\mathscr{S} = \frac{1}{2\tau}\left(\frac{a}{v}\right)$; ϑ, the total deflection angle; λ; and μ. Since an integration for each set of input parameters takes more than an hour on the 650, this problem is being considered for the 704. (Sam Howry for Gaja Alaga and George Merkel)

A specialized program was written for the IBM 650 which computes the performance of a magnet from certain design equations. First the program finds the smallest positive root of the transcendental equations

$$\frac{J_n(x)}{Y_n(x)} - \frac{J_{n+2}(kx)}{Y_{n+2}(kx)} = 0 \quad \text{for } n = 0, 1, \quad 0 < k < 1,$$

using the method of false position. For the values of k used, good first-approximation bounds are known, since the root is just beyond the first positive root of $J_n(x)$. By using these roots, $\bar{X}_0$ and $\bar{X}_1$, and for a given r_i (inner radius) and r_0 (outer radius), the following functions are computed:

$$j\ (\theta, r), \quad \text{(current density)}$$

$$B_{\bar{r}}\ (\theta, r),$$

$$B_{\bar{\theta}}\ (\theta, r),$$

$$\alpha \equiv \tan^{-1}\left(\frac{B_{\bar{\theta}}}{B_{\bar{r}}}\right),$$

$$B(r, \theta) \equiv B\bar{\theta}/\sin\alpha$$

for

$$\theta = 0,\ 180^0,\ \Delta\theta = 6^0,$$

$$r = r_i,\ r_0 \quad \Delta r \approx 5 \text{ cm}.$$

(Sam Howry for Bob Smith)

The orbits of charged particles in the Bevatron magnetic field were computed on the IBM 650 Computer. (Victor Brady for George Masek, Peter Hoang, and members of the Alvarez group.)

An IBM 650 program was written to integrate angular diffraction curves in the optical model of the nucleus. These curves were for various target materials for a 5-Bev neutron-scattering experiment. Included in the computations were corrections to the theoretical curves required by diffraction by the apparatus. (Michael Lourié for John Atkinson and Richard Kurz)

An IBM 650 program was written to analyze data from a medium-energy $\pi^{\pm}$ scattering experiment. A linear least-squares fit was made between the accidental rate and the apparent absorption rate of particles. (Michael Lourié for Tim Devlin)

Judd

An IBM 650 program RECOIL was written to determine the energy spectrum of elastically scattered protons from given track lengths of the scattered protons. (Carl Quong for R. Lehman)

Problem ALPHONSO has been largely completed. Nucleon-nucleon elastic and inelastic cross sections in nuclear matter have been computed for a range of incident-particle energies of 0 to 7 Bev and of struck-particle Fermi energies of 0 to 50 Mev for nuclear matter in which the neutron and proton Fermi energies are the same. A few cases for unlike neutron-proton Fermi energies have been processed. Cross sections for scattering with one particle remaining in a 10-Mev range above its Fermi energy, with Fermi energies of 0 (free space) and 20 Mev, and incident-particle energies between 50 Mev and 6 Bev, have been computed. The above work was done on the IBM 701. (Thomas Clements for Lester Winsberg)

An IBM 701 program, WOOD, was written to solve the differential equation $y'' + y\frac{1}{x} - n^2 \frac{y}{x^2} + y - y^3 = 0$ subject to $y(0) = 0$, $y(\infty) = 1$ for $n = 1, 2, 3$. (Jonathan Young for Harold Wu)

The work of computing eigenvalues and eigenvectors for the hydrogen molecular ion was completed on the IBM 701 Computer. (Victor Brady for John Hiskes)

A program was written for use on the IBM 704 which will calculate, by means of a least-squares fit, the magnetic dipole and for a set of observational data in the form of frequency of observed resonance versus magnetic field for arbitrary hyperfine transitions. In addition to obtaining the dipoles and quadrupoles for a fixed g_J, the program will vary and improve g_J if desired. The eigenvalues of the Hamiltonian for the hyperfine structure of the atom in an applied magnetic field are calculated as a function of the magnetic field. These values are used as starting values for the iterative process of calculating the magnetic dipole, electric quadrupole, and g_J (if desired) constants and their respective errors. Finally the energy levels and residuals for each datum are calculated. (Donald H. Zurlinden for William F. Nierenberg)

Work was started on a program to compute equilibrium shapes of charged liquid drops on the IBM 704 Computer. (Victor Brady for W. Swiatecki)

88-Inch Cyclotron Design Problems

Design studies for the 88-inch cyclotron required IBM 650 codes to process the data from the model magnet. Codes were written for use in the calculation of trimming-coil currents to produce isochronism. IBM 650 programs prepare the input for an IBM 704 linear programming (LP) code which completes the solution of the problem. These codes also process model-magnet measurements and help put the 704 output into usable form. A 650 LP code was used to test this method for solving the trim-coil problem.

Model-magnet measurements were processed with SEACY codes to prepare input for 704 orbit codes, "Ill-Tempered Five," of MURA. This input consists of a representation of the field by a Fourier series in angle and a polynomial in radius.

Judd

Miscellaneous hand calculations, curve plots, etc, were required for these design studies. (Ardith Kenney for Al Garren)

DORO, a code to process magnet measurements into a form suitable for use with Oak Ridge orbit codes, was written. Among other things DORO calculates corrections to the radial profile of the magnetic field necessary to produce isochronism, and if desired corrects the measurements accordingly.

Model-magnet measurements were processed with DORO and the Oak Ridge code to determine corrections to the radial profile required for isochronism, and to prepare tables of radial and vertical oscillation frequencies in the cyclotron for various energies and particles.

By using required isochronous corrections calculated by DORO and certain model-magnet measurements processed by Ardith Kenney's IBM 650 code as input for the RAND LP code, trimming-coil current settings have been obtained from the RAND code that produce an optimum field shape for isochronism.

The measurements as processed by the 650 code SEACY have been used to run MURA'S ITV code to compute orbits for use in studies of the extraction problem. (Douglas Brainard for A. Garren)

Budget Assistance

Schedule 92, the budget problem, was run on the IBM 650. Budget checks are run periodically to determine what costs are actually developing during the fiscal year in relation to certain effort predictions. The results indicate what modifications, if any, need to be made in the effort figures.

The Schedule 92 program is now in the process of being rewritten for the IBM 650. The chief advantages of the new program are that it will permit check runs to be made for either the Berkeley or Livermore site separately, and that it will allow for unlimited expansion of the number of support and scientific groups.

An additional program is being written to organize the results of the machine runs into the proper form for the final budget presentation. (Ardith Kenney for Budget Department)

Operation of IBM 704

Preparations were completed in cooperation with the Campus Computing Center of the University of California at Berkeley for installing and operating an IBM 704. The machine was installed in October in Campbell Hall on the campus and started operating in the last week of October. The laboratory has the hours 8:00 to 9:00 a.m., 2:00 to 4:00 p.m. and 8:00 p.m. - midnight daily, plus additional time as needed up to 80 hours per week. We may use more than 80 hours per week if time is available from the computer center, with a readjustment of cost according to the ratio of time actually used by the Laboratory to the total time available to the Laboratory and computing center combined. We expect to use the machine immediately for all time not required by the computer center.

A subroutine library for the IBM 704 has been set up and procedures established for handling material received from SHARE (a 704 users' organization). We now have on file: program write-ups for some 700 subroutines, binary and (or) symbolic cards for about 100 subroutines, reference catalogues which list and describe all available subroutines, and lists of corrections to previously distributed material.

We have rechecked some important 704 subroutines and in some cases have rewritten the corresponding program write-ups and mass-reproduced these. The collection of write-ups for these important programs (the Minimum Package) is now available to users of the 704. (Harold Hanerfeld for Kent Curtis)

The input-output routines in the SHARE "minimum package" for the IBM 704 were checked. Modifications necessary to adapt them for use on a 32K drumless machine were made and writeups were changed to reflect these changes or remove possible sources of confusion. (Charles Leuhr for Kent Curtis)

Memory-dump routine with several options suitable for the 32,000-word IBM 704 is being written. (W. H. Hutchinson for Kent Curtis)

The assembly routine 9AP9 written at Livermore for the IBM 709 is being modified for use on our 704. It will replace UA SAP 3-7. It is capable of assembling any SAP program but writes a PACT tape which can be used conveniently for program modification or reassembly. (Graham Campbell for Kent Curtis)

A guidebook has been written that will be distributed to Lawrence Radiation Laboratory users of the 704 Computer Center. The guidebook was designed to be of aid in the application of the 704, and covers material for the SHARE Symbolic Assembly Program and FORTRAN II. (Donald H. Zurlinden for Kent Curtis)

New Acquisitions

Preparations have also been made to purchase the IBM 650 located at the Laboratory. This purchase is in accordance with an educational contribution offer made by IBM to the Laboratory whereby we pay 40% of the present value of the machine as the total purchase price. A separate maintenance contract with a 20% educational contribution is being written with IBM to provide maintenance for the 650.

We have also ordered an IBM 1401. This machine has a 4000-character core memory, an 800-card-per-minute card reader, a 250-card-per-minute punch, a 600-line-per-minute printer, and four tape units. It will be used as peripheral equipment for the IBM 704 and for Laboratory accounting problems. Delivery is expected in 12 to 18 months.

Plans for the installation of an IBM 704 or 709 at the Laboratory are still in a state of flux. No final decision has been reached with respect to either the location of this facility or the date of installation. It is expected that the Laboratory will use the 704 in Campbell Hall on the campus until it is no longer possible to get adequate time on that machine. Before a crisis develops with respect to time on the campus 704 we shall install a 704 or 709 at the Laboratory. This machine and the 1401 will be jointly housed to form an integrated computing facility.

The IBM 650 is to be moved to the Bldg. 70 annex when that is completed. (Kent Curtis)

PHYSICS RESEARCH

Edward J. Lofgren in Charge

$\bar{p}$-p CROSS SECTIONS AT HIGH ENERGIES

Rafael Armenteros,[*] Charles A. Coombes,[†] Bruce Cork,
Glen R. Lambertson, and William A. Wenzel

During this interval the interactions of high-energy antiprotons in hydrogen were measured. An abstract of the results was given at the Honolulu meeting of the American Physical Society.[1]

DECAY ASYMMETRY OF Σ^+ AND Λ^0 HYPERONS

Rodney L. Cook,[§] Bruce Cork, James W. Cronin,[**]
Leroy Kerth, and William A. Wenzel

The asymmetry in the decay of Σ^+ and Λ^0 hyperons produced by 1.0-Bev/c pions in hydrogen was measured. An abstract of the results was submitted to the New York City meeting of the American Physical Society.[2]

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[*] On leave of absence from the Laboratoire de Physique, Ecole Polytechnique, Paris, and CNRS, France.

[†] Now at Idaho State College, Pocatello, Idaho.

[§] Now at Brookhaven National Laboratory, Upton, Long Island, New York.

[**] Now at Palmer Physical Laboratory, Princeton University, Princeton, New Jersey.

[1] Armenteros, Coombes, Cork, Lambertson, and Wenzel, $\bar{p}$-p Cross Sections at High Energies, Bull. Am. Phys. Soc. 4, 354 (1959).

[2] Cool, Cork, Cronin, Kerth, and Wenzel, Decay Asymmetry of Σ^+ and Λ^0 Hyperons.

PHYSICS RESEARCH

Burton A. Moyer and A. C. Helmholz in charge

PION-NUCLEON TOTAL CROSS SECTIONS

Thomas T. Devlin

Total cross sections of π^+ and π^- mesons on hydrogen were measured at the Bevatron in July. The energy range was 500 to 1700 Mev. Three peaks in the cross sections were observed. The π^- results gave sharp maxima at 600 and 905 Mev (lab), and the π^+ has a broad maximum at 1370 Mev.

In all, the cross section was measured at seventy energies. Special attention was given to the 905-Mev and 1370-Mev maxima. We also tried to find a peak in the π^- cross section at 1370 Mev. The preliminary data indicate that it is present, but the evidence is not as conclusive as for the other peaks. A broad plateau in the cross section is more consistent with the data.

The energy resolution of the beam and the counting statistics should give an uncertainty of approximately 2% in the final results.

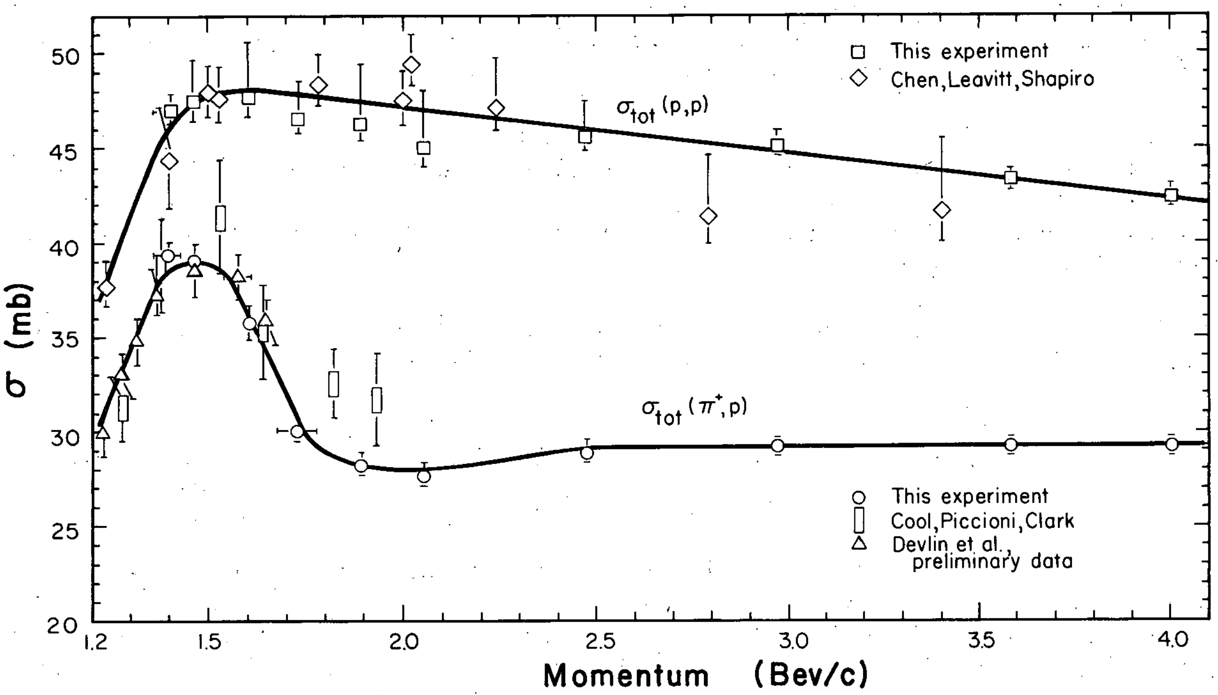
HIGH-ENERGY CROSS SECTIONS FOR POSITIVE PIONS AND PROTONS

Michael J. Longo

During June a counter experiment was conducted at the Bevatron to measure total cross sections for π^+ mesons and protons on hydrogen and other nuclei. In order to obtain pions of the highest possible momentum the beam was brought out of the machine through a window on the inside radius. Extensive magnetic shielding to reduce the Bevatron's leakage field was required along most of the beam line. Paraffin shielding was successfully employed to reduce the high particle flux within the Bevatron ring.

It was found that the π^+-proton total cross section went through a maximum of about 39.2 millibarns near 1.5 Bev/c, and between 2.4 and 4.0 Bev/c was essentially constant at 29.2 mb. The latter value agrees well with values obtained for the $(\pi^- \text{-p})$ cross sections at high energies. The proton-proton total cross sections were found to decrease gradually from about 48 mb at 1.5 Bev/c to 42.4 mb at 40 Bev/c. See Fig. 1. The accuracy of these measurements was generally between 2% and 3%. In the regions where our data overlapped those of other experimenters the agreement was generally good.

Measurements of the cross sections for positive pions and protons on D, Be, C, Al, and Cu nuclei in both good and poor geometry were also made. The analysis of these data, when complete, will yield information on the radii as well as the total and absorption cross sections of these nuclei for both positive pions and protons.



MU-18604

Fig. 1. Total (π^+, p) (p, p) cross sections vs. momentum.

NUCLEAR EXCITATION FROM μ^- CAPTURE

Selig N. Kaplan

The neutrons emitted following capture have been counted for Al, Ca, Fe, Ag, I, Au, and Pb. Preliminary analysis of the experimental results give, for the average multiplicities, $\overline{\nu}_{Ca} = 0.73 \pm 0.06$, $\overline{\nu}_{Fe} = 1.11 \pm 0.05$, $\overline{\nu}_{Ag} = 1.45 \pm 0.06$, $\overline{\nu}_{I} = 1.40 \pm 0.06$, $\overline{\nu}_{Au} = 1.56 \pm 0.06$, $\overline{\nu}_{Pb} = 1.60 \pm 0.06$. Further analysis of the data to determine the multiplicity distributions is now in progress. Studies are currently being made to determine a satisfactory technique for measuring the neutron energy spectrum.

Incidental to the above work, U^{238} fission induced by μ^- capture has been detected with a gas scintillator. These results have been reported in the literature.[1]

ANTINEUTRONS

John A. Poirier

The Bevatron run with a separated antiproton beam incident upon a 72-in. liquid hydrogen bubble chamber is completed; 120,000 pictures have been obtained and rough-scanned. Analysis of these pictures will allow us to obtain a cross section for the charge exchange of antiprotons into antineutrons as well as the cross section for the subsequent annihilation of the antineutron with a proton.

The Bevatron run was divided into two parts, one at 1.63 Bev/c incident antiproton momentum and the second at 2.00 Bev/c momentum. The intensity and cleanliness of the antiproton beam was better at the lower momentum; our analysis is now concentrated on this part. Enough events have been found in the rough scan to define the two cross sections to about 10% accuracy.

Further analysis of the annihilation stars for possible π-π angular correlations (as have been observed in antiproton annihilation) should be possible. There is also evidence that sometimes the antiproton charge exchange is accompanied by one or more π's. Data on these effects will have poor statistics.

The experiment has been performed jointly with the Alvarez Group.

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[1] Phys. Rev. Letters 3, 234 (1959).

Moyer-Helmholz

p-p-π^0 EXPERIMENT

Gilbert Mead

The experiment designed to measure the gamma-ray spectrum arising from π^0 mesons produced in p-p collisions at various angles with respect to the incoming proton beam is presently in the midst of a second cyclotron run (November, 1959). A preliminary run at 5 deg was completed in June. This experiment used a scintillator pair spectrometer with twelve counters which was designed to fit into a large H magnet (Orion) recently purchased for general use at the cyclotron. It also uses a specially designed 36-channel 6×6 coincidence circuit. To obtain additional information on the low-energy part of the gamma spectrum, a 180-deg spectrometer, also with twelve scintillator counters, has been designed and built for the present run. The two spectrometers are expected to span the region from 30 to 700 Mev very nicely. So far the run is operating smoothly and according to schedule.

The only comparable data on gamma-ray spectra from this process come from a series of Russian experiments with their 660-Mev cyclotron. So far our results seem to show a quite serious discrepancy with their data. We are attempting to do a very careful job in order to fully determine the degree of discrepancy. Our preliminary results indicate that π^0 production at these cyclotron energies seems to possess a marked contribution proportional to $\cos^2\theta$ (θ being defined as the center-of-mass angle between the incoming proton and π^0 meson), rather than predominantly isotropic, as the Russian data indicate.

PION PRODUCTION BY PIONS

Victor Perez-Mendez

One run was held at the 184-in. cyclotron on the reaction $\pi^- + p \rightarrow \pi^+ + \pi^- + n$. The incident pion energies used were 427 and 371 Mev. This reaction was unambiguously identified by detecting the π^+ produced. The energy distribution of the π^+ was measured as a function of the laboratory-system angle of production. Integration over energy and angle gave the total cross section $\sigma = 3.3 \pm 0.7$ mb at 427 Mev and $\sigma = 1.9 \pm 0.4$ mb at 371 Mev.

These cross sections, together with the previous data obtained at lower energies, confirm that the static-model calculation which takes into account only a direct pion-nucleon interaction fails to predict the measured effect by an order of magnitude. The most plausible interpretation of this discrepancy is that it is due to a pion-pion interaction.

A complete report on this experiment has been written (UCRL-8778) and a brief version has been published.[2]

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[2] Walton A. Perkins, III, John C. Caris, Robert W. Kenney, and Victor Perez-Mendez, Pion Production by Pions, (submitted to Physical Review); brief version, Phys. Rev. Letters **3**, 56 (1959).

MOMENTUM DISTRIBUTION OF QUASI DEUTERONS

Robert J. Cence

The energy spectrum of protons produced at 60 deg by 245 ± 15-Mev selected photons on carbon has been measured. This spectrum covered a range from 100 to 250 Mev. The data were analyzed by using the quasi-deuteron model of Levinger.[3] A reasonable fit to the data was obtained by assuming that the centers of mass of all possible neutron-proton pairs had a momentum distribution given by the sum of two Gaussian functions,

$$\frac{d^3N}{dP^3_{np}} \propto 0.36 \exp\left(-P^2_{nD}/4\ ME_1\right) + 0.07 + \exp\left(P^2_{np}/\ 4\ ME_2\right) ,$$

where $E_1 = 1.6$ Mev, $E_2 = 30$ Mev. Only the qualitative aspects of this distribution are considered significant.

π^- - p ELASTIC AND CHARGE-EXCHANGE SCATTERING

John C. Caris and Lester K. Goodwin

The differential cross section for the elastic scattering is being measured in the energy range from 235 to 427 Mev for the incident pion in the laboratory frame of reference. The data have been analyzed for measurements at 370 and 427 Mev, and clear evidence for D-wave scattering has been found.

In the differential cross section for charge-exchange scattering the data have been analyzed for pion energies of 260, 317, and 371 Mev. Here again evidence for D-wave scattering has been found at 371 Mev but not at the lower energies.

Both these experiments are still in progress and accumulating data at lower energies extending down as far as 235 Mev.

Computer programs for analyzing the differential cross sections in terms of the various partial waves have been established, and should deliver the final information from these runs within a few months from now.

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[3] J. S. Levinger, Phys. Rev. 84, 43 (1951).

Moyer-Helmholz

SYNCHROTRON EXPERIMENTS

Robert W. Kenney

The reaction $\gamma + p \rightarrow \pi^+ + n$ has been measured near threshold in the 4-in. hydrogen bubble chamber, with emphasis upon accurate monitoring, in order to clarify uncertainties in this energy region. Complete angular and photon-energy distributions will be reported.

The analysis of the reaction

$$\begin{aligned} \gamma + d &\rightarrow \pi^- + 2p \\ &\rightarrow \pi^+ + 2n \end{aligned}$$

is nearly complete. The ratio $\pi^-/\pi^+ = 1.39 \pm 0.19$ will be revised with additional data from the analysis, and the Chew-Low Pololog̃y Theory will be invoked to measure the cross section for $\gamma + n \rightarrow \pi^- + p$. In conjunction with the data for $\gamma + p \rightarrow \pi^+ + n$ taken in the same geometry, a ratio π^-/π^+ will be found independent of Coulomb and deuteron ground-state corrections. Evidence has been found for the validity of the impulse approximation applied to the reaction

$$\begin{aligned} \gamma + d &\rightarrow \pi^- + 2p \\ &\rightarrow \pi^+ + 2n . \end{aligned}$$

BEVATRON NEUTRON EXPERIMENTS

John H. Atkinson

The Bevatron neutron cross-section measurements have been successfully completed. Total and reaction cross sections were measured for 5-Bev neutrons in Pb, Cu, Al, and C and total cross sections in Sn and liquid H. The counting equipment was removed from the Bevatron in October. Final reports and papers are now being prepared as a project report.[4]

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[4] John H. Atkinson, 5-Bev Neutron Cross Sections in Hydrogen and Other Elements (Thesis), UCRL-8966, Nov. 1959.

PHYSICS RESEARCH

Wilson M. Powell and Robert W. Birge in charge

THE ELASTIC SCATTERING OF 5-Bev π^- MESONS ON HYDROGEN

The elastic scattering of 5-Bev negative pions on hydrogen has been observed in the 30-inch propane chamber. Approximately (7 ± 3)% of the events called elastic are probably background. The observed angular distribution is strongly peaked forward, suggesting that diffraction is the dominant process at this energy. The theoretical analysis of the distribution is in terms of the optical model. The proton acts like a partially opaque sphere of radius 1.04×10^{-13} cm ± 5%. From the extrapolated value of $\frac{d\sigma(0)}{d\Omega} = 29.8 \pm 10\%$ mb/sterad in the center-of-mass system, a value of 29.1 ± 2.9 mb was calculated for the total hydrogen cross section. The opacity of the sphere is thus 0.69 ± 0.05. The total elastic cross section is found to be 5.6 ± 0.5 mb.

PION-PION INTERACTIONS

An attempt to determine the π-π cross section from the reaction $\pi^- + p \rightarrow \pi^- + p + \pi^0$ is in progress. The experiment follows the proposal of Chew and Low, Phys. Rev. 113, 1640 (1959). With 5.0-Bev π^- on propane we restrict the two-prong events to those in which the positive prong stops in the 30-inch chamber and has no decay. In addition, the events are passed through extensive 5-body kinematic criteria.

π^--p ELASTIC SCATTERING NEAR THE SECOND RESONANCE

An analysis is being made of the angular distributions of π^--p elastic scatterings at 600, 650, and 750 Mev. The purpose is to determine the angular-momentum and parity states of the 600-Mev maximum in the π^--p total cross section. Approximately 1000 good events are expected at each energy. The rest of the events are discarded because they were inelastic or did not come through the thin window. This latter group constitute nearly half the events. Scanning and measuring is essentially finished. An extensive investigation of measurement and multiple-scattering error has been made, and a process of separation of elastic from inelastic events has been developed.

NEGATIVE CASCADES

The lifetime and Q values of the cascade particle (Ξ^-) obtained from 20 events were reported at the Kiev Conference. Work is now being done to determine the flux of K^- producing the cascades in order to obtain a production cross section.

NEUTRAL CASCADE PRODUCTION

Photographs taken with the 1.15-Bev/c K^--meson beam have been scanned for stars which apparently emit both a Λ^0 hyperon and a θ^0 meson. The majority of these are caused by background pions in the beam, giving the process

$\pi^- + p \rightarrow \Lambda^0 + \theta^0$. A dynamical analysis is being carried out to determine whether any events are due to Ξ^0 hyperons according to the reaction $K^- + p \rightarrow \Xi^0 + \theta^0$, $\Xi^0 \rightarrow \Lambda^0 + \pi^0$.

THE PROTON HELICITY FROM Λ^0 DECAY

We have measured 850 cases in which the proton from Λ^0 decay subsequently scatters in propane. From these scatterings it is possible to determine the transverse polarization of the protons. One can then obtain the value of the initial longitudinal polarization of the proton in the c.m. system of the Λ^0. To date about 200 cases have been completely analyzed that satisfy the criteria of elastic scattering.

Because the maximum-likelihood method used in the analysis picks out those few events with high analyzing power, better statistics are needed to obtain a reliable answer. The analysis is continuing. Preliminary results were reported at the meeting of the American Physical Society in Hawaii.

REGENERATION OF K_1 NEUTRAL MESONS FROM DIFFRACTION SCATTERING OF K_2 MESONS

In order to prove a most significant consequence of the Pais-Gell-Mann particle-mixture theory, the 30-inch propane bubble chamber was exposed to a beam of K_2 particles of 700 Mev/c. Approximately one K_2 particle crossed the chamber for each Bevatron pulse. All together, 200,000 pictures were taken, one-half with a 6-in. iron plate in the chamber, the other half with a 1.5-in. plate made half of iron, half of lead, so that the effects of iron and lead could be separated. Regeneration of K_1 follows either from the coherent effect of the nucleus as a whole (diffraction regeneration) or from the coherent action of all nuclei in the plate (transmission regeneration). Up to now we have recognized 150 K_1 particles, of which approximately fifteen appear due to diffraction regeneration in the thin iron plate and ten to diffraction regeneration in the thin lead plate. The particle-mixture theory is thus confirmed. There appears to be no appreciable transmission-regeneration component in the thick plate: using a method of calculation similar to that of M. L. Good, we deduce that the mass difference between K_1 and K_2 is finite, probably more than (h/2) x mean life of K_1.

Preliminary results were given in an invited paper on θ^0_2 interactions with nuclei by Francis Muller at the American Physical Society meeting in Hawaii.

Powell-Birge

HYPERFRAGMENT LIFETIME

The research group at Wisconsin, directed by Jack Fry, is analyzing our high-energy K^- film to obtain the lifetime of hyperfragments. Preliminary results indicate that the lifetime is appreciably shorter than that of the free Λ^0.

Λ^0-p SCATTERING

In the 1.1-Bev/c K^- film there are approximately 20,000 Λ^0. The film is being scanned for possible Λ^0-p elastic scatterings. The number of scatterings is expected to be about 100. In this experiment it is known that the nonscattered Λ^0 are not polarized; the up-down asymmetry of the scattered Λ^0 can therefore be used as an analyzer of the spin dependence of the Λ^0-proton interaction.

DATA ANALYSIS FOR THE 30-INCH PROPANE BUBBLE CHAMBER

PROGRAM DEVELOPMENT

Most of the programming effort has been devoted to the development of a comprehensive group of computer codes designed to aid in the numerical analysis of bubble chamber data. With bubble chamber experiments now reaching the range of tens of thousands of events, a very considerable hand effort is required to correlate and check for completeness all data pertaining to each of the events. It is better that the computer shall provide the mechanics for supervision of the data processing as well as mechanizing the numerical computations performed upon separate events. The experimenter is then freed of the chore of shepherding the data of each individual event through the complex maze of numerical calculations, and is instead given the opportunity to study the data from the viewpoint of physics, not bookkeeping. To reach this goal, and to increase the accuracy and efficiency of the bubble chamber analysis programs, three levels of program systems are being developed for the IBM 704.

FOG IV, a program system that operates upon data produced by measuring microscopes (or Franckensteins) and other sources, and produces angle-momentum descriptions of individual tracks observed in the bubble chamber, is the first of these to be completed. This system, comprising approximately 12,000 words of 704 coding, accepts and checks input data, performs the numerical computations, correlates these with all previously processed information pertaining to the event, and stores the data in a magnetic tape library for the experiment. A by-product of this processing is a summary over a specified period of the errors and inconsistencies found in the input. Thus, quality control of measuring equipment and its operators is provided, and diagnostic information is given to indicate the corrective action necessary to reduce the frequency of the input errors. During the half year of this report, coding and debugging of this program system have been completed.

CLOUDY IV, a program system for the identification of observed events with particular nuclear interactions, has been planned in detail during the period of this report. Input is contained in the tape library that is the FOG IV output. A sequence of calculations appropriate to individual events is performed in accordance with a procedure previously specified by the experimenter. These calculations include the application of constraints to improve the measured data, and the calculation of physically significant parameters describing the event. It is expected that coding for major classes of events will be completed during the next half year.

Powell-Birge

FAIR, a program system for the summarization of selected events, has been planned during the period of this report. This system will accept CLOUDY IV output as its input, and will selectively include requested parameters describing events in scatter diagrams, histograms, and other summarizing media that are displayed as cathode-ray-tube output of the 704. The selection criteria of events to be summarized are specified by the experimenter, and then CLOUDY calculations are scanned for events meeting these criteria. Those accepted are included in the summary, and any previously calculated parameters can be displayed as plotted points in the output displays. The portions of this system of programs that are affected by the other systems have been planned in detail during the period of this report.

Several programs for the IBM 650 have been completed during this half year. They include two programs that calculate tables describing the kinematics of three-body final states involved in the meson-cloud studies of π-p interactions, a program that rotates events from the measurement frame into any other frame, a program that introduces kinematical constraints into the description of V^0 decays, and a program that determines certain vector descriptions of p-p annihilations. These programs contain a total of approximately 4500 words of code.

Data Processing

The number of origins measured and numerically analyzed for each of the experiments is indicated in the following table. All data were obtained in the 30-inch propane bubble chamber.

Experiment	Processed May-October	Processed to date
5.2-Bev/c π^- mesons	183	7,234
750-Mev/c π^- mesons	12,411	22,606
1.1-Bev/c K^- mesons	5,931	6,954
1.1-Bev/c antiprotons	1,408	2,846
700-Mev/c θ^0_2 mesons	5,981	5,981

Approximately 17,456 of these origins were measured on the propane-chamber Franckenstein, and the remaining 8,458 origins were measured on the two digitized microscopes. The microscopes were operated for a total of 2640 hours and the Franckenstein for 2910 hours. The rates are therefore 3.2 events per hour for the microscopes, and 6.0 events per hour for the Franckenstein.

Powell-Birge

PAPERS ISSUED

Goldhaber, Fowler, Goldhaber, Hoang, Kalogeropoulos, and Powell, Pion-Pion Correlations in Antiproton Annihilation Events, Phys. Rev. Letters 3, 181 (1959).

Richard Lander, Wilson Powell, and Howard White, Parity Conservation in Hyperon Production by 1.15-Bev/c K^- Mesons on Propane, Phys. Rev. Letters 3, 236 (1959).

Lewis E. Agnew, Jr., Antiproton Interactions in Hydrogen and Carbon Below 200 Mev (Thesis), UCRL-8785, July 1959.

Richard G. Thomas, Jr., Elastic Scattering of 5-Bev π^- Mesons on Hydrogen (Thesis), UCRL-8965, November 1959.

Robert W. Birge, Hans J. Courant, Robert E. Lanou, Jr., and Marian N. Whitehead, K^+ Charge Exchange. Part I. Search for K^+ Charge Exchange, (submitted to Physical Review).

Marian Whitehead, Robert E. Lanou, Jr., Robert W. Birge, Wilson M. Powell, and William B. Fowler, K^+ Charge Exchange. Part II. Production of K^0 Mesons by Charge Exchange of K^+ in Propane, (submitted to Physical Review).

Marian Whitehead, Robert E. Lanou, Jr., Victor Cook, and Robert W. Birge, K^+ Charge Exchange. Part III. Charge-Exchange Cross Sections of K^+ in Tungsten, Carbon, Copper, and Emulsion. (Submitted to Physical Review).

Wilson M. Powell, Interpretation of Results from Propane and Other Heavy-Liquid Chambers, Invited Paper given at CERN International Conference on High-Energy Accelerators and Instrumentation, 1959.

PHYSICS RESEARCH

Emilio Segrè in charge

CYCLOTRON EXPERIMENTS

ELASTIC π^+-p SCATTERING EXPERIMENTS AND PHASE-SHIFT ANALYSIS

James H. Foote, Owen Chamberlain, Ernest Rogers, Herbert M. Steiner,
Clyde Wiegand, and Tom Ypsilantis

We have completed a series of experiments dealing with π^+-p elastic scattering at the 184-inch cyclotron. The energy of the incident pion beam was 310 Mev. We measured the differential cross section, the total cross section, and the polarization of the recoil protons as a function of the angle of scattering. We have analyzed the data in terms of S-, P-, and D-wave phase shifts. Because of the relatively high accuracy of the cross-section data and the inclusion of the polarization data, we have succeeded in obtaining a single acceptable set of phase shifts. The errors on these phase shifts are less than one degree.

A large part of our data (and a description of the phase-shift analysis) is contained in a report by Foote, Chamberlain, Rogers, Steiner, Wiegand, and Ypsilantis, Phase Shifts in π^+-p Scattering at 310 Mev (submitted to Phys. Rev. Letters).

We are planning similar experiments over a wide range of incident pion energies.

SEARCH FOR A NEUTRAL MESON OF ZERO I SPIN

Norman Booth, Owen Chamberlain, and Ernest Rogers

A search has been made for a neutral meson of zero I spin by means of the reaction $d + d \rightarrow He^4 + \pi^0_0$. No evidence was found for the existence of the π^0_0 in the mass range zero to 1.7 times the $\pi^\pm$ mass. The upper limit of the cross section was about 7×10^{-32} cm^2 for $\pi^0_0 \sim \pi^\pm$ mass.

The reaction was studied by using 460-Mev deuterons from the 184-inch cyclotron and a liquid deuterium target. Alpha particles produced at 0 deg in the laboratory system were selected by momentum analysis and by a counter telescope which measured time of flight, dE/dx, and differential range.

Although the π^0_0 result was negative, the experiment sets a limit on the validity of charge independence. We hope to be able to give an estimate of this limit soon.

A paper on this work will be presented at the Pasadena meeting of the American Physical Society (UCRL-8944 Abstract).

Segrè

n-p SCATTERING CROSS SECTION

Rudolf R. Larsen

Measurement of the n-p differential cross section at 740 Mev in the neighborhood of 180 deg center-of-mass angle, as previously outlined,[1] is in progress. From this measurement it is possible to extract the value of the pion-nucleon coupling constant by using a method suggested by Chew.[2]

The angular distribution in the interval 180 to 140 deg (c.m.) angle has been investigated. Completion of the angular distribution and measurement of the absolute cross section is scheduled for December-January 1960 on the 184-inch cyclotron.

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[1] Rudolf R. Larsen in Physics Division Semiannual Report, UCRL-8545, Dec. 1958, p. 49

[2] Geoffrey F. Chew, A Proposal for Determining the Pion-Nucleon Coupling Constant from Nucleon-Nucleon Scattering, UCRL-8283, May 1959.

Segrè

BEVATRON EXPERIMENTS

ANTIPROTONS IN PROPANE

Lewis Agnew, Tom Elioff, William B. Fowler, Richard Lander,
Wilson M. Powell, Emilio Segrè, Herbert M. Steiner,
Howard White, Clyde Wiegand, and Tom Ypsilantis

The run of antiprotons in the propane bubble chamber performed early in 1958 has been analyzed and its results are contained in Agnew's thesis.[3]

A slightly shorter version of this thesis will be published in the Physical Review.

p-$\overline{p}$ CROSS SECTIONS

Tom Elioff, Lewis Agnew, Owen Chamberlain, Herbert M. Steiner,
Clyde Wiegand, and Tom Ypsilantis

A counter run on proton-antiproton and deuteron-antiproton collisions was performed and is now being thoroughly analyzed.

Preliminary results on it have been published.[4] The scattering and annihilation and charge-exchange cross sections up to about 1068 Mev have been measured, and some of the anomalies which had been previously indicated are now resolved.

$\pi + p \rightarrow K + \Sigma$ REACTION

Joseph Lach, Norman Booth, Leonard Auerbach, William B. Johnson,
Richard R. Lander, Herbert M. Steiner, and Clyde Wiegand

A counter run on this reaction has given unsatisfactory results.

DATA STORAGE

Clyde Wiegand

Developments are in progress to feed counter information into computers. At present an intermediate stage, in which the information is on tape, is being tested.

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[3] Lewis E. Agnew, Jr., Antiproton Interactions in Hydrogen and Carbon below 200 Mev (Thesis), UCRL-8785, July 1959.

[4] Elioff, Agnew, Chamberlain, Steiner, Wiegand, and Ypsilantis, $\overline{p}$-p Cross Sections from 534 to 1068 Mev, Phys. Rev. Letters 3, 285 (1959).

Segrè

π-π INTERACTION

Tom Ypsilantis, Clyde Wiegand, William B. Johnson,
Herbert M. Steiner, and Owen Chamberlain

Preparations are being started to study this reaction,

$$\pi^- + p \rightarrow n + \pi^+ + \pi^- ,$$

which is interesting—according to Chew—for the investigation of the π-π interaction.

THE STUDY OF ANTIPROTON ANNIHILATION EVENTS IN PHOTOGRAPHIC EMULSIONS

Gerson Goldhaber and Rein Silberberg

Following completion of a paper on $\bar{p}$-n annihilation,[1] we have proceeded with some further analyses of $\bar{p}$ stars in emulsions. These involve the scattering on hydrogen at low energies, and other details on annihilation stars. The study by the emulsion method is now completed.

THE STUDY OF ANTIPROTON INTERACTIONS IN THE[*] 30-INCH BUBBLE CHAMBER AT A MOMENTUM OF 1.05 Bev/c

Gerson Goldhaber, Theodore Kalogeropoulos, Won Yong Lee,
Rein Silberberg, and Ted Stubbs

A difference in the distribution in angle between like and unlike pion pairs was discovered.[2] Calculations to understand the observed effect in terms of the invariant statistical model as modified by the introduction of Bose statistical correlation functions is in progress (in conjunction with A. Pais). So far no evidence for a specific pion-pion resonance in the T = 1 state has been observed.

As pointed out by A. Pais, the $\bar{p}$-H interaction is invariant under parity, charge conjugation, and CP. The annihilation events thus afford a test for possible violations of these principles in strong interactions. No violations have been observed in various tests carried out for more than 1000 vector triples of the type $\bar{p}$, π^+, π^-.

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[1] Chamberlain, Goldhaber, Jauneau, Kalogeropoulos, Segrè, and Silberberg, Antiproton-Nucleon Annihilation Process. II, Phys. Rev. 113, 1616 (1959).

[2] Goldhaber, Fowler, Goldhaber, Hoang, Kalogeropoulos, and Powell, Pion-Pion Correlations in Antiproton Annihilation Events, Phys. Rev. Letters 3, 181 (1959) .

[*] This work was carried out in conjunction with William B. Fowler, Wilson M. Powell, and Harold White, and also with S. Goldhaber and T. F. Hoang of the Lofgren Group.

Segrè

STUDY OF THE K^+ - H AND K^+ - D REACTION*

Gerson Goldhaber and Ted Stubbs

A run is in progress at the Bevatron with the 15-inch hydrogen bubble chamber filled with deuterium and hydrogen. A good deal of effort over the past year went into the study, design, and construction of a 700-Mev/c K^+ beam which is now set up at the Bevatron. The beam yields about 10 K^+ mesons per pulse, with less than 2% in background beam particles.

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*In conjunction with Sulamith Goldhaber of the Lofgren Group, Hugh Bradner of the Alvarez Group, and Harold K. Ticho and Donald Stork of UCLA.

Segrè

ACCELERATOR OPERATION AND DEVELOPMENT

BEVATRON

Edward J. Lofgren in charge

The report for February through April 1959 has been issued separately as "Bevatron Operation and Development XXI," UCRL-8927, October 1959; reports for May through July and August through October are to be issued as XXII and XXIII.

184-INCH CYCLOTRON

Robert L. Thornton in charge

Reported by James T. Vale

No material was received for this section.

60-INCH CYCLOTRON

W. B. Jones in charge

OPERATION

Beam Splitter

Often the number of particles available in a cyclotron far exceeds the demands of the experiment. On these occasions, it would be very advantageous to have an auxiliary experiment ready that could use these particles. At present, when the supply exceeds the demand, we reduce the intensity or collimate the beam more severely to limit the number of particles available to the experimentalist. However, it is possible to divide the cyclotron beam into two separate parts, of comparable intensities and available to two separate experimental stations.

A piece of equipment that could "split" the beam was designed, fabricated, and tested at Crocker Laboratory. It was found to fulfill the requirements with a beam loss of less than 30%. We do not have enough space to split the beam and then steer the two separate parts into two experimental stations; however, if we can establish a technique for such a device, it can be used in conjunction with the 88-inch cyclotron.

The splitting of the beam is identical with the experiment performed by Rutherford and Robinson in determining the charge-to-mass ratio of the alpha particle. The particles were allowed to pass between two plates at different potentials. If we are given $\underline{V}$ = the difference of potential between the plates, $\underline{d}$ = the distance between the plates, $\underline{L}$ = the length of the plates, and $\underline{v}$ = the velocity of the alpha particle, then the deflection $\underline{y}$ due to the electric field is given by

$$y = \frac{1}{2}\,\frac{V}{d}\,\frac{e}{M}\,\frac{L^2}{v^2}\,. \qquad (1)$$

Our apparatus, consisting of three parallel carbon plates 0.08 cm thick, 45 cm long, and 7 cm high, is housed in a plexiglass tube of 13.5 cm i. d. (see Fig. 2). The distance between the two outer plates is adjustable, although for this experiment it was held constant: the outer plates were 2.1 cm from the center plate.

A brass tube section, fitted to the back end of the plexiglass tube, extends 72.0 cm beyond the end of the carbon plates. The back part of the brass tube has a 5-mil aluminum foil window which the beam passes through. A small glass diffusion pump is connected to the brass tube. Ilford emulsion plates were placed directly behind the aluminum window to show the positions of the beams. The front end of the plexiglass tube is connected to a beam port. A high-dc-voltage power supply is connected to the center carbon plate, and the two outer plates are grounded.

With the power supply off, the center carbon plate was raised out of the beam path, and the beam was allowed to pass through and irradiate an emulsion plate. The burns taken in this manner were used for aligning and focusing the beam. The carbon plate was then returned to the original setting. An electrometer lead was connected to the center plate. Two electrometer leads were placed behind the 5-mil aluminum window in such a way that the beam could be monitored on each side of the center carbon plate. Thirty per cent of the beam was recorded on the center carbon plate, and 35% on each of the other two target leads. These percentages can be changed by varying the focusing magnet. We found that the beam could be moved from one side of the center plate to the other by varying the cyclotron magnet and deflector.

The voltage was varied from 0 kv up to 70 kv, and the beam separation was recorded on the emulsion plates. With the high voltage on, it was not possible to monitor the beam hitting the center plate.

For the 48-Mev alpha particles of the 60-inch cyclotron at Crocker Laboratory, Eq. (1) can be reduced to

$$y = 1.04 \times 10^{-5}\ V. \qquad (2)$$

Using similar triangles, we have a ratio between two sides:

$$\frac{(L/2)}{(L/2) + 72.0} = \frac{y}{x}\,, \qquad (3)$$

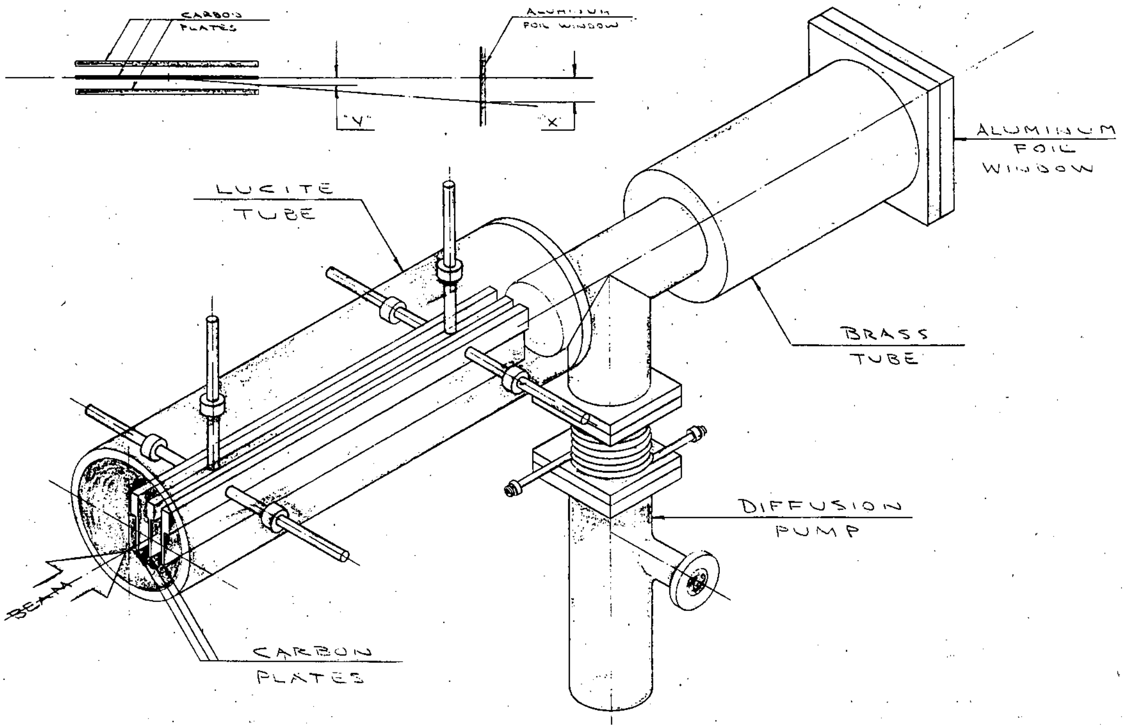
where $\underline{x}$ is the deflection at the emulsion plate. This becomes

$$x = 4.2y, \qquad (4)$$

$$x = 4.37 \times 10^{-5}\ V. \qquad (5)$$

The experimental data are recorded in Table I, and are in good agreement with the theoretical data.

Jones


CARBON PLATES
ALUMINUM FOIL WINDOW
"Y"
"X"
LUCITE TUBE
ALUMINUM FOIL WINDOW
BRASS TUBE
DIFFUSION PUMP
BEAM
CARBON PLATES

MU-18873

Fig. 2. Beam Splitter.

Table I

Deflections of beam in beam splitter

V (kv)	y (calc.) (cm)	x (calc.) (cm)	$\Delta x/x$ (calc.) ±	x (exptl) (cm)
5	0.052	0.218	0.045	0.30
10	0.104	0.437	0.048	0.45
15	0.156	0.655	0.054	0.60
20	0.208	0.874	0.061	0.80
25	0.260	1.09	0.068	1.05
30	0.312	1.31	0.077	1.25
35	0.364	1.53	0.086	1.50
40	0.416	1.75	0.095	1.75
45	0.468	1.97	0.104	2.00
50	0.520	2.18	0.114	2.20
55	0.572	2.40	0.123	2.40
60	0.624	2.62	0.134	2.55
65	0.676	2.84	0.144	2.75
70	0.728	3.06	0.154	2.90

Summary of Usage

Summary of usage as prepared by Peter McWalters for this 6-month period:

Alpha bombardments	1,469.7 hr
Proton bombardments	456.6 hr
Deuteron bombardments	212.2 hr
Beryllium bombardments	85.1 hr
Experimental bombardments	195.5 hr
Operations Total	2,419.1 hr
Outage	232.8 hr
Available Time	2,651.9 hr
Shutdown	1,708.1 hr
Holidays	56.0 hr
Total Time	4,416.0 hr

An operating efficiency of 91.2% was maintained throughout this 6-month period.

Jones

HEAVY-ION LINEAR ACCELERATOR

Chester M. Van Atta in charge

Reported by Edward L. Hubbard

The planned shielding over the top of the accelerator will cut off the flow of air that has been used to cool the rf cavities, therefore a water cooling system has been added to the accelerator. Installation of the water cooling system caused the accelerator to be shut down on day shift from June through September.

Cleanup of the curium spill that occurred early in July required complete shut down of operations for 2 weeks and allowed only limited operation for the rest of the month.

In September two of the A2332 tubes used in the main rf amplifiers developed grid-to-cathode shorts. To make tests to determine the cause of these failures and make the changes indicated, operations were shut down completely for 2 weeks in October.

The time available to experimenters during the period was used as follows:

Chemistry		88.0%
Heavy elements	18.8%	
Coulomb excitation	13.6	
Nuclear Reactions Group	11.6	
Fission Counting Group	5.3	
Other	39.0	
Physics		6.6
Medical Physics		5.4

SYNCHROTRON

Rudin M. Johnson in charge

No material was received for this section.

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