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PHYSICS DIVISION SEMIANNUAL REPORT

November 1962 through April 1963

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GENERAL PHYSICS RESEARCH

PHYSICS RESEARCH

Luis W. Alvarez in charge

RESEARCH WITH BUBBLE CHAMBERS

The work reported below has been done--as indicated at the end of each subsection--by Gideon Alexander (GA), Margaret H. Alston (MHA), Luis W. Alvarez (LWA), Jared A. Anderson (JAA), Angela Barbaro-Galtieri (AB-G), Pierre Bastien (PB) J. Peter Berge (JPB), Bevalyn B. Crawford (BBC), Frank S. Crawford, Jr. (FSC), Orin I. Dahl (OID), Philippe Eberhard (PE), Massimiliano Ferro-Luzzi (MF-L), Robert E. Foulks (REF), Robert L. Golden (RLG), Ronald A. Grossman (RAG), J. Richard Hubbard (JRH), Robert W. Huff (RWH), William E. Humphrey (WEH), Afzaal Hussain (AH), Darrell O. Huwe (DOH), Laurance D. Jacobs (LDJ), George R. Kalbfleisch (GRK), Janos Kirz (JK), Joseph E. Lannutti (JEL), Sylvia Limentani (SL), Jim Lindsey (JL), Lester J. Lloyd (LJL), Gerald A. Lynch (GAL), Bogdan C. Maglić (BCM), Gerald Meisner (GM), Deane Merrill (DM), Joseph J. Murray (JJM), Alan Natapoff (AN), LeRoy R. Price (LRP), Alan Rittenberg (AR), Arthur H. Rosenfeld (AHR), Ronald R. Ross (RRR), Joseph A. Schwartz (JAS), Janice Button Shafer (JBS), Frank Shively (FS), Dan Siegel (DS), Gerald A. Smith (GAS), Frank T. Solmitz (FTS), M. Lynn Stevenson (MLS), Harold K. Ticho (HKT), Robert D. Tripp (RDT), Mason B. Watson (MBW), Charles G. Wohl (CGW), Stanley G. Wojcicki (SGW), Nguyen-Huu Xuong (NHX).

The K 72 Experiment (72-Inch Chamber)

General Information

The K 72 experiment is a study of the K^-p and K^-d interactions over the energy range from 1.0 to 1.7 BeV/c. The total exposure has consisted of 789 rolls in hydrogen and 47 rolls in deuterium. As of the end of this report period, all of the film has been scanned twice and approximately 50% of all the events (except two prongs) have been measured.

The Y_1^* (1660 MeV) Hyperon

A study of approximately 10,000 events of various topologies produced by the 1.51-BeV/c K^- mesons has yielded definite evidence for the existence of an excited hyperon with a mass of 1660 ± 10 MeV and a width of 40 ± 10 MeV. The production cross section for this resonance at this energy

is approximately 0.4 mb. The branching ratios for the modes KN: $\Sigma\pi$: $\Lambda\pi$: $\Sigma\pi\pi$: $\Lambda\pi\pi$ have been determined to be < 1: 6: 7: 4: 4, respectively. No information on the spin or parity has been obtained because of limited statistics and the predominance of the other resonant states. The data have been published.[1]
(LWA, MHA, MF-L, DOH, GRK, DHM, JJM, AHR, JBS, FTS, and SGW)

SU_3 Symmetry Model and the Partial Decay Widths of the Known Resonances

A compilation was made of the partial decay widths of the known resonances and they were shown to agree quite well with the predictions of the SU_3 model proposed by Gell-Mann[2] and Ne'eman.[3] Furthermore, it was shown that all the known baryons and mesons could be fitted very well into the framework of the SU_3 model.[4]
(AHR in collaboration with S. L. Glashow, Department of Physics, University of California, Berkeley.)

Reaction $K^- + p \rightarrow Y^{*\pm} + \pi^{\pm}$

The spin and parity of the Y_1^* (1385 MeV) lambda-pion resonance were firmly established through the analysis of events from the K-72 run which fitted the hypothesis $K^- + p \rightarrow \Lambda + \pi^+ + \pi^-$. (An earlier experiment by Colley et al.[5] at Columbia University gave weak indication of the same parity conclusion if the spin determination were taken from another experiment; however, the spin itself had not been clearly established because of disagreements among various experimental results, caused mostly by the difficulty in assessing background effects. (See Ely et al.[6]) The decay of the $Y_1^{*\pm} \rightarrow \Lambda + \pi^{\pm}$ in a total of 1650 events produced by 1.22-BeV/c K^- mesons was analyzed to determine the angular distribution of the decay lambda and also to determine the polarization (spin orientation) of the lambda. The variation of the latter with the decay angle of the lambda showed that the only acceptable spin and parity assignments for the Y_1^* are spin 3/2 and even relative Y_1^*-Λ parity (if spins greater than 3/2 are assumed unlikely). The other three "possible" states for spin 1/2 or 3/2 were each found to have a

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1. Luis W. Alvarez, Margaret H. Alston, Massimiliano Ferro-Luzzi, Darrell O. Huwe, George R. Kalbfleisch, Donald H. Miller, Joseph J. Murray, Arthur H. Rosenfeld, Janice B. Shafer, and Stanley G. Wojcicki, Phys. Rev. Letters 10, 184 (1963).
2. Murray Gell-Mann, Phys. Rev. 125, 1067 (1962); California Institute of Technology Report CTSL-20, 1961 (unpublished).
3. Y. Ne'eman, Nucl. Phys. 26, 222 (1961).
4. Sheldon L. Glashow and Arthur H. Rosenfeld, Phys. Rev. Letters 10, 192 (1963).
5. D. Colley et al., in International Conference on High-Energy Nuclear Physics, Geneva, 1962, p. 315.
6. Robert P. Ely, Sun Yiu Fung, George Gidal, Yu-Li Pan, Wilson Powell, and Howard White, Phys. Rev. Letters 7, 461 (1961).

probability of only 1 in 10^5 of being correct. The determination of spin-parity of 3/2-even for the Y_1^* placed it in a very reasonable position in the organizational scheme for particles (resonances) known as "unitary symmetry" and thereby gave further credibility to the theory. This work was published.[7]

Further study is being made of the Y_1^* production over a wide range of incident momenta.
(DOH, JJM, JBS)

Study of the Reaction $K^- + p \rightarrow \Lambda + \omega$

Properties of the ω meson have been undergoing further study in events from the K-72 run satisfying $K^- + p \rightarrow \Lambda + \omega$. The branching ratio of neutral decay ($\omega \rightarrow \pi^0 + \gamma$) to the predominant $\omega \rightarrow \pi^+\pi^-\pi^0$ decay was determined to greater accuracy than before (0.11 ± 0.03). Also the natural (true) width of the three-pion decay was studied and the experimental value reduced appreciably from the upper limit established previously (the estimate now being 4 ± 4 MeV). Evidence for the two-pion decay mode was found; and if the possibility (1 chance in 300) of its being a statistical fluctuation were ignored, the branching ratio of $\omega \rightarrow \pi^+\pi^-/\omega \rightarrow \pi^+\pi^-\pi^0$ could be evaluated to be 0.045 ± 0.016. An upper limit was put on the branching ratio for another rare decay mode, $\omega \rightarrow e^+ + e^-$ (less than 0.01 of the three-pion decay rate). Still another decay mode, $\omega \rightarrow \pi^+ + \pi^- + \gamma$, is undergoing further study.

At present a systematic study is being made of the reaction $K^- + p \rightarrow \Lambda + \omega$ as a function of K^- momentum in an attempt to understand the mechanism of production and perhaps to learn about possible intermediate hyperon-pion states. This information is being correlated with the momentum dependence of other reactions following from the initial state $K^- + p$.
(MF-L, DOH, JJM, JBS, FTS, and MLS)

Reaction $K^- + p \rightarrow \bar{K}^0 + \pi^- + p$

The measurements of the examples of the reaction $K^- + p \rightarrow \bar{K}^0 + \pi^- + p$ have been almost completed. At all momenta the reaction appears to proceed approximately 75% of the time via the production of the 890-MeV K^* and the other 25% of the time by the three-body mode.

Definite evidence has been obtained for a new $K\pi$ excited state with a mass of 723 ± 3 MeV and a width less than 12 MeV.[8] These parameters are in excellent agreement with those obtained from the $\pi 72$ experiment. The cross section for the production of this resonance falls from approximately 80 μb at 1 BeV/c to less than 10 μb at 1.7 BeV/c. The spin and parity are still unknown, 0^+ and 1^- being the obvious possibilities.

Work is continuing on the study of the production mechanism of the 890-MeV K^* at various energies.
(MHA, GRK, and SGW)

---

7. Janice B. Shafer, Joseph J. Murray, and Darrell O. Huwe, Phys. Rev. Letters 10, 179 (1963).

8. Stanley G. Wojcicki, George R. Kalbfleisch, and Margaret H. Alston, Production of K Mesons in K^-p Interactions, submitted to Phys. Letters.

Search for a T = 3/2 Resonance in the K-π System

The reaction $K^- + n \rightarrow K^- + \pi^- + p$ is being analyzed in 20,000 pictures taken with the 72-inch bubble chamber filled with deuterium. The beam momentum was 1.51 BeV/c. So far there are 480 events fitting the above reaction. A motivation for studying this process was the investigation of the existence of a T = 3/2 $K\pi$ resonant state; this initial state, being a pure I = 1 state, strongly favors T = 3/2 $K\pi$ formation with respect to similar reactions in hydrogen. There is no evidence of any resonance in this system in the mass range $620 < M(K\pi) < 1100$ MeV. However, the K^-p mass distribution shows a large peak corresponding to production of Y_0^* (1520) as well as evidence for the production of a resonant state at about M(Kp) = 1785 MeV.
(AB-G, AH, RDT)

Search for a T = 2 Resonance in the $\Sigma\pi$ System

Using film from the K-72 experiment we have searched for a resonance in the doubly charged $\Sigma\pi$ system. The reactions studied were
(1) $K^- + p \rightarrow \Sigma^\pm + \pi^\mp + \pi^+ + \pi^-$ at 1.51 and 1.71 BeV/c incident momentum,
(2) $K^- + d \rightarrow \Sigma^\pm + \pi^\mp + \pi^- + (p)$ at 1.51 BeV/c incident momentum.

In the hydrogen film we had a total sample of about 1660 and 460 events at 1.51 and 1.71 BeV/c respectively. All of these have been measured and analyzed. We found that the resonances $Y_0^*(1405)$, $Y_0^*(1520)$, and $Y_1^*(1660)$ were all being formed approximately in the ratio 3:1:1 at both momenta. However, no evidence for a resonance in either the $\Sigma^+\pi^+$ or $\Sigma^-\pi^-$ system was observed.

In deuterium the K^- interacts with the neutron in the deuteron and gives the possibility of forming a resonant $\Sigma^-\pi^-$ system in $\Sigma^-2\pi$ events. A total of 1500 events was measured, giving about 450 examples of reaction (2) in which there was a low-momentum proton. In this case also $Y_0^*(1405)$ and $Y_0^*(1520)$ were formed but no Y_2^* was observed.
(MHA, AB-G, AHR, SGW)

K^-p Interactions in the Region of 1050 MeV/c

In order to study interactions in the region of the broad bump in the total K^-p cross section at 1050 MeV/c, the 72-inch hydrogen bubble chamber was exposed to K^- beams with incident momenta of 1050 and 1110 MeV/c. The amount of data corresponds to about 300 events/mb. Almost all events have been measured. A study of the reaction $K^-p \rightarrow \bar{K}^0 n$ gives a cross section of about 9 mb, or about 5 or 6 mb above background. A fit of the center-of-mass production angle to the series $\Sigma A_n \cos^n\theta$ indicates that terms up to $\cos^5\theta$ are necessary and sufficient. The coefficients vary rapidly in the region.

The $K^-p \rightarrow \Sigma\pi$ data have also been studied. The cross section for each charge channel is about 2 mb, which is 1/2 to 1 mb above the cross sections observed for these reactions at 850 MeV/c and at 1220 MeV/c. Powers of $\cos\theta$ up to at least fifth order, and perhaps sixth order, are required to fit the production angular distributions. The polarization of the Σ^+ as determined by measuring the quantity (αP) for the decay $\Sigma^+ \rightarrow p\pi^0$ is found to be close to 100%.

Addition of these data to those of Beall et al.[9] indicates that the contributions to the bump in the total cross section comes predominantly (about 80%) from the $\bar{K}N$ channels, and that the pion-hyperon channels contribute relatively little.
(MHA, GRK, DHM, CGW, SGW)

Study of Ξ^- and Ξ^0 Hyperons

The lifetimes of the Ξ^- and Ξ^0 hyperons have been determined to be

$$\tau_{\Xi^-} = 1.75 \pm 0.07 \times 10^{-10} \text{ sec}$$

and

$$\tau_{\Xi^0} = 2.50^{+.36}_{-.27} \times 10^{-10} \text{ sec.}$$

These numbers are based upon 798 Ξ^- and 83 Ξ^0 hyperons that were produced in the reactions

$$K^- + p \rightarrow \Xi^- + K^+$$

and

$$K^- + p \rightarrow \Xi^0 + K^0.$$

Work is continuing on the other parameters of the Ξ hyperons.
(LWA, JPB, JRH, GRK, JBS, FTS, MLS, and HKT)

Upper Limit on the $\Delta S = 2$ Decay of Ξ^-

Samples of Ξ^- produced by the 1.51-BeV/c K^- have been examined for possible examples of $\Delta S = 2$ decay mode. No case of the decay $\Xi^- \rightarrow n + \pi^-$ has been found among 200 Ξ^-, setting an upper limit on the $\Delta S = 2$ decay mode of 1/2%. This work will be published in the Physical Review.
(MHA, MF-L, AHR, SGW)

The π72 Experiment (72-Inch Chamber)

General Information

The π-72 experiment is a study of π^-p and π^-d interactions over the energy region from 1.5 to 2.36 BeV/c. The total exposure consisted of 453 rolls in hydrogen and 58 rolls in deuterium. As of the end of this report period the analysis of all strange-particle events in hydrogen ($\approx$ 12,000) is nearly complete. In addition, 11,000 two-prong interactions in hydrogen have been measured and analyzed. In the deuterium film the analysis of the $\pi^-d \rightarrow \Sigma^-\pi^-K^+p$ has been completed.

The Reaction $\pi^- + p \rightarrow K\bar{K}N$

Two final states have been studied, $\pi^- + p \rightarrow K_1^0 + K^- + p$ and $K_1^0 + K_1^0 + n$. Apart from some production of Y_0^*(1520 MeV), as seen in the effective-mass

9. E. F. Beall et al., in International Conference on High-Energy Nuclear Physics, Geneva, 1962, p. 368.

distributions of the $\bar{K}N$ pair, we find that the distribution in momentum transfer to the recoil nucleon is consistent with the assumption that most $K\bar{K}$ pairs are produced peripherally in this reaction (one-pion exchange). The $K\bar{K}$ effective-mass distributions show an enhancement at low $K\bar{K}$ mass in the neutral system, while the charged system is consistent with phase-space predictions. Since the decay angular distribution of the neutral low-mass $K_1^0K_1^0$ system is flat (except for Y_0^* events), the enhancement is interpreted as a strong s-wave final-state $K\bar{K}$ interaction in the I = 0 state. Such an interpretation yields a satisfactory fit to the data for a complex scattering length A = ±(4 to 6) + 0.3i. These results have been published.[10]

Two other final states, $\pi^- + p \rightarrow K_1^0K_2^0n$ and K^+K^-n, have been looked for. The K^+K^-n channel can be found only if one of the charged K's decays. This sample is biased toward low-momentum K's and is substantially contaminated by false events. The analysis of the K^+K^-n is proceeding. The $K_1^0K_2^0n$ final state can be observed directly in events with two V's (one a K_1^0 and one a K_2^0). Five such events were found, all of which are consistent with production of $Y_0^*(1520) + K_1^0$ or $Y_0^*(1520) + K_2^0$, with the Y_0^* decaying to $K_2^0 + n$ or $K_1^0 + n$ respectively. This final state can be ascertained indirectly in events that have a K_1^0 and a neutron-proton recoil observed, by subtracting out the expected number of $K_1^0K_1^0n$ events which would be observed in this way. The subtraction leaves 5 ± 5 events of the type $K_1^0K_2^0n$. The $K_1^0K_2^0$ mass distribution in all these events shows no enhancement at low mass, which placed an upper limit on ϕ production by $\pi^- + p \rightarrow \phi + n$ of approximately 10 μb at ≈ 2 BeV/c.
(GA, OID, LDJ, GRK, DHM, AR, JAS, GAS)

The Reaction $\pi^- + p \rightarrow \Sigma^0K^+\pi^-$

At P = 2.17 and 2.25 BeV/c we have observed 209 $\Sigma^0K^+\pi^-$ events. The reaction $\pi^-p \rightarrow \Sigma^0K^+\pi^-$ proceeds through the intermediate state Σ^0K^{*0} 70% of the time. The analysis of the data indicates that the K^* is aligned, confirming that the spin is nonzero. By use of the known spin-parity assignment of 1^-, the data have been analyzed in terms of an exchange model, where the K^* is produced by K and K^* exchange between the π^- and proton in the initial state. The model gives results in reasonable agreement with the data.[11]
(GA, OID, RWH, GRK, DM, JAS, GAS)

The Reaction $\pi^- + d \rightarrow \Sigma^-\pi^-K^+p$

The deuterium exposure to 2.26-BeV/c π^- was analyzed to look for the T = 2 $\Sigma\pi$ resonance predicted by "global symmetry."[12] A total of

10. Gideon Alexander, Orin I. Dahl, L. Jacobs, G. R. Kalbfleisch, D. H. Miller, Alan Rittenberg, Joseph Schwartz and Gerald A. Smith, Final State Interactions in the $\pi^- + p \rightarrow K + \bar{K} + N$ Reaction, Phys. Rev. Letters 9, 460 (1962).

11. George A. Smith, Joseph Schwartz, Donald H. Miller, George R. Kalbfleisch, Robert W. Huff, Orin I. Dahl and Gideon Alexander, Evidence for K^* Spin Alignment and Possible Exchange Mechanism in the Reaction $\pi^-p \rightarrow \Sigma K^*$, Phys. Rev. Letters 10, 138 (1963).

12. G. R. Kalbfleisch, G. Alexander, O. I. Dahl, D. H. Miller, A. Rittenberg and G. A. Smith, Study of the I = 2 $\Sigma\pi$ System in the $\pi + N$ Interactions, submitted to Phys. Letters.

123 $\Sigma^-\pi^-K^+p$ events were found and analyzed. The reaction proceeds essentially as $\pi^- + n \rightarrow \Sigma^-\pi^-K^+$, with the proton of the deuteron being a spectator. The reaction is found to be dominated by $K^*(\Sigma^-K^{*0})$, as was the $\pi^- + p \rightarrow \Sigma^0K^*$ reaction discussed above. The K^* also exhibits the alignment of the Σ^0K^{*0} reaction. No evidence is observed for a $\Sigma^-\pi^-$ resonance at a mass < 1800 MeV, contrary to the expectations of global symmetry. Although a weak $\Sigma\pi$ I = 2 resonance cannot be ruled out, its absence in this experiment appears incompatible with "global-symmetry"-type theories.[12]
(GA, OID, GRK, DM, AR, and GAS)

Reactions $\pi^- + p \rightarrow \Lambda + K^0, \Sigma^0 + K^0, \Sigma^- + K^+$

The angular distributions and polarizations of the YK final states are being analyzed as a function of c.m. energy. The Λ and Σ^0 have large backward peaks in the angular distribution as well as a smaller forward peak. The Σ^- go forward, but not sharply. The Λ from ΛK^0 are polarized, with the polarization being dependent on the production angle. The net polarization (integrated over all angles) is small, except at 1.5 BeV/c. The angular distributions change distinctly in the region of the 2-BeV/c π^+p resonances. The analysis is continuing and preliminary results were reported at the American Physical Society, Washington.[13]
(GA, OID, LJ, GRK, DM, JAS, and GAS)

The 725-MeV $K\pi$ Enhancement (the κ)

The statistical significance of the κ in the $\pi^- + p \rightarrow \Sigma^- K^+$ is approximately 3 standard deviations, which is not quite conclusive by itself. However, the 725-MeV $K\pi$ enhancement seems well established in view of recent developments in the $K^-p \rightarrow \bar{K}^0\pi^-p$ reaction.[14]
(GA, OID, LJ, GRK, DM, GAS)

Two-Pronged Interactions

About 11,000 two prongs at 2.05, 2.17, and 2.36 BeV/c have been measured. The angular distributions of the elastic events will be analyzed. The inelastic channels $p\pi^-\pi^0$ and $\pi^+\pi^-n$ have been examined for the production of resonant states. The ρ is produced quite copiously. Various N^*'s are also seen.

In particular, the $\pi^+\pi^-$ effective-mass distributions were examined for enhancements at 1 to 1.1 BeV in order to find a 2π decay of the $K_1^0K_1^0$ enhancement and at 1.25 BeV in order to observe the f^0. The $\pi^+\pi^-$ distributions show no such enhancements. However, this does not consititute a definitive statement on the branching ratios, since 11,000 two prongs represents a very small proportion of the total data, and only puts a rather large upper limit on these branching ratios. Lack of enhancements cannot be ruled out.
(OID, GRK, DM, GAS)

13. Gerald A. Smith, Study of π^-p Interactions at 1.5-2.4 BeV/c, [invited paper, Session WA(3)]; Associated Production in the Momentum Range 1.4-2.4 BeV/c [contributed paper, Session LA(6)], American Physical Society, Washington, D. C., April 22-25, 1963.

14. Donald H. Miller, Gideon Alexander, Orin I. Dahl, Laurance Jacobs, George R. Kalbfleisch, and Gerald A. Smith, A $K\pi$ Resonant State at 726 MeV, submitted to Phys. Letters.

Low-Energy π^- Experiment (72-Inch Chamber)

This experiment is a study of the reaction $\pi^- + p \rightarrow \pi^- + \pi^+ + n$ in the energy range from 360 to 800 MeV.[15] Cross sections, Dalitz plots, and $\pi^+\pi^-$ and $\pi^{\pm}n$ mass spectra have been obtained at beam energies of 360, 430, 460, 480, 555, 605, 673, and 780 MeV. No clear evidence was found for any $\pi^+\pi^-$ resonances between threshold and 680 MeV. However, a strong preference for high $\pi^+\pi^-$ effective masses has been observed, especially at the lowest beam energies. This anomaly can be ascribed to the I = 0 state of the π-π system.
(JK, JAS, RDT)

Associated-Production Experiment (72-Inch Chamber)

General Information

This experiment is a study of π^-p and π^+p interactions at energies in the vicinity of the associated-production threshold.

$\pi^+ + p \rightarrow \pi^+ + p + \eta$ with Incident π^+ of 1170 MeV/c

(a) The branching ratio $\eta \rightarrow \pi^+\pi^-\gamma/\eta \rightarrow \pi^+\pi^-\pi^0$ has been determined, starting with a sample of 4500 four-pronged events.[16]
(b) The branching ratios $\eta \rightarrow \gamma\gamma/\pi^+\pi^-\pi^0$ and $3\pi^0/\pi^+\pi^-\pi^0$ have been determined, by use of both internal conversion and hydrogen conversion, e^+e^-.[17]
(c) It is found that $\pi^+p \rightarrow \pi^+p\pi^+\pi^-\pi^0$ goes almost entirely via η production, with π^+p in the 3-3 resonance.
(d) No evidence is seen for any η-p or η-π^+ resonance at this energy.
(e) Angular distributions and absolute cross sections will be examined.
(FSC, LJL, LRP, RAG in collaboration with E. C. Fowler, Duke University)

$\pi^- + p \rightarrow \pi^+ + p + \pi^+ + \pi^-$, Incident π^+ of 1170 MeV/c

About 3000 events were obtained. They are being studied for possible new resonances.
(ESC, LJL, RG, LRP).

$\pi^+ + p \rightarrow \pi^+ + p + \eta$ and $\pi^+p\pi^+\pi^-$ with π^+ of 1050 MeV/c

Measurements of 4-prongs in this film has begun, with several objectives:
(a) Measure η cross section.
(b) If the η yield is sufficient at this lower momentum, the branching ratios can be improved, both because of increased statistics and because in the case of the neutral decays the background due to $\pi^+p \rightarrow \pi^+p\pi^0\pi^0$ should be smaller.
(FSC, LJL, RG, LRP)

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15. J. Kirz, J. Schwartz, and R. Tripp, Reaction $\pi^- + p \rightarrow \pi^-\pi + N$ from 360 to 800 MeV, to be published.

16. Earle C. Fowler, Frank S. Crawford, Jr., Lester J. Lloyd, Ronald A. Grossman and LeRoy Price, Phys. Rev. Letters 10, 110 (1963).

17. Frank S. Crawford, Jr., Lester J. Lloyd, and Earle C. Fowler, Experimental Determination of the Neutral Branching Ratios of the η Meson, to be published by Phys. Rev. Letters.

$\pi^- + p \rightarrow \Sigma^- + K^+$ and $\Sigma^0 + K^0$ with π^- of 1170 MeV/c

Angular distributions and cross sections, when compared with previous results for $\pi^+ + p \rightarrow \Sigma^+ + K^+$, show that the "triangle" of charge independence is "flat" in the backward-hyperon hemisphere. According to Michel's theorem, and the measured large Σ^+ polarization, both Σ^0 and Σ^- should then have a large polarization. These polarizations are being studied at present.
(JAA and FSC)

Three-Body Decays of K_1^0 and K_2^0

The "to the last event" disposition of events arising from $\pi^- + p \rightarrow \Lambda + K^0$ is nearing completion, in the second half of the 1035-MeV/c film and in the 1170-MeV/c film. The final number of events should be about three times the 25 already published on the $\Delta S = \Delta Q$ and $\Delta I = 1/2$ rules.
(FSC, DY, GM in collaboration with D. Stern, University of Wisconsin).

Sign of $m(K_1^0)-m(K_2^0)$

Following the method suggested by Camerini, Fry, and Gaidos (Sign of the K_1-K_2 Mass Difference, Department of Physics, University of Wisconsin preprint), we hope to determine m_1-m_2 by using $(K^0, \bar{K}^0) + p \rightarrow K_1^0 p$ or $K_2^0 p$. Second scanning and measuring are in process.
(BBC, FSC, RLG, and GM).

$\pi^- p$ Charge Exchange

The properties of the 72-inch H_2 bubble chamber as a slow-secondary-neutron spectrometer have been examined, particularly the technique for reducing background due to stray neutron flux from the Bevatron. The results were positive and, in an experiment nearing completion, have been applied to a low-statistics measurement of the forward differential cross section for π^--p charge-exchange scattering at 1.03 BeV/c.

In the latter experiment some few dozens of rolls were scanned initially, of which a third proved suitable for final analysis. An average of about three events per roll was found to fit the charge-exchange hypothesis with a χ^2 parameter below 2.0 for forward scattering π^0's, $0.8 < \cos\theta$ cm < 1.0. When noise-reducing criteria are applied, the overall detection efficiency for such events is of the order of 5%.
(AN)

Antiproton Experiment (72-Inch Chamber)

The analysis of two-prong events in the antiproton experiment has been completed. Monte Carlo calculations (Program FAKE) were used to estimate the effects of misinterpreting events. Elastic-scattering data show a secondary diffraction peak at about 82° in the center-of-mass system. Single-pion production is found to be consistent with charge-conjugation invariance. In these events the predominance of low momentum transfer exceeds that predicted by the single-pion-exchange formula of Chew and Low. A search was made for annihilations yielding only two mesons, with 33 such events found out of 3569 measured events. The K^- distribution in $\bar{p} + p \rightarrow K^- + K^+$ shows a strong forward peaking, whereas the π^- in $\bar{p} + p \rightarrow \pi^- + \pi^+$ does not.

The analysis produced nine cross-section measurements as follows:

$\bar{p} + p \rightarrow$	$\pi^- + \pi^+$	119 ± 30 μb
	$K^- + K^+$	55 ± 18 μb
	$\bar{p} + p$	$31.1 \pm 2.$ mb
	$\bar{p} + p + \pi^0$	1.85 ± 0.22 mb
	$p + \bar{n} + \pi^-$	1.19 ± 0.16 mb
	$\bar{p} + n + \pi^+$	1.00 ± 0.16 mb
	$\pi^- + \pi^+ + \pi^0$	1.58 ± 0.26 mb
	Annihilations with K's	3.4 ± 0.5 mb
	Other annihilations	13.0 ± 1.5 mb

Two companion papers based on the above-described analysis have been submitted to The Physical Review.[18, 19]
(PE, REF, GRK, JEL, SL, GAL, BCM, JBS, MLS, and N-HX)

Low-Energy K^-p Experiments (15-Inch Chamber)

K^-p Interactions in the Region 250 to 513 MeV/c

The computer analysis of the low-momentum K^-p interactions (250 to 513 MeV/c) has been completed. The 10,000 events composing the elastic and charge-exchange angular distributions and hyperon-production angular distributions and polarizations are presented to the computer in terms of 257 data points. These are fitted to nonresonant S-, P-, and D-wave amplitudes and a resonant amplitude of the Breit-Wigner form corresponding to $Y_0^*(1520)$. An extensive search for χ^2 minima was done on the 7090 computer under various assumptions for the spin and parity of the resonance. Only a $D_{3/2}$ resonance in both Kp and $\Sigma\pi$ yielded a satisfactory fit, leading to the unambiguous conclusion of negative $KN\Sigma$ parity. This work has been submitted for publication.[20]
(MF-L, RDT, MBW)

K^-p Interactions in the Region 620 to 850 MeV/c

The analysis of all the cross sections and angular distributions for the K^-p system at 620, 760, and 850 MeV/c has been completed. At 760 MeV/c the $Y_1^*(1660)$ is observed in the two- and three-body final states.

18. Gerald A. Lynch, Robert E. Foulks, George R. Kalbfleisch, Sylvia Limentani, Janice B. Shafer, M. Lynn Stevenson, and Nguyen-Huu Xuong, Interactions of 1.61-BeV/c Antiprotons in Hydrogen Involving Two Outgoing Charged Particles, UCRL-10632, Jan. 17, 1963, submitted to Phys. Rev.

19. Gerald A. Lynch, Philippe Eberhard, George R. Kalbfleisch, Joseph E. Lannutti, Bogdan C. Maglić, Janice B. Shafer, M. Lynn Stevenson, and Nguyen-Huu Xuong, Two-Meson Annihilations of 1.61-BeV/c Antiprotons in Hydrogen, UCRL-10633, Jan. 17, 1963, submitted to Phys. Rev.

20. M. B. Watson, M. Ferro-Luzzi, and R. D. Tripp, Analysis of $Y_0^*(1520)$ and Determination of Σ Parity, submitted to Phys. Rev.

The branching ratios for $\Lambda\pi$: $\Sigma\pi$: $\Lambda\pi\pi$: $\Sigma\pi\pi$: $\bar{K}N$ are found to be $<3:7:5:8:23$. Spin 1/2 seems very unlikely for $Y_1^*(1660)$, on the basis of unitarity arguments. Also the absence of $\cos^3\theta$ terms in the angular distributions leads us to believe that spin 3/2 for $Y_1^*(1660)$ is more consistent with our data than spin 5/2. The lack of data points at closely spaced momentum intervals in the resonance region prevents us from obtaining an energy dependence of the $\sin\theta \cos\theta$ terms in the polarizations, and therefore nothing can be said about the parity of $Y_1^*(1660)$. This work has been published.[21]

The events $K^- + p \rightarrow \Lambda + \pi^+ + \pi^-$ in this momentum region have been reanalyzed along the lines indicated by Dalitz and Miller in an attempt to determine the spin of the $Y_1^*(1385)$. The results seem to indicate that within the limits of the model, S 1/2 gives a better Y^* decay fit than P 3/2. The dependence of the result on the model assumptions is being studied.
(PB and JPB)

K63 and π63 Experiments (72-Inch Chamber)

General Information

The K63 and π63 experiments are meant to extend to higher energies the study of K^-p and π^-p interactions begun in the K72 and π72 experiments.

The π63 Experiment

The 72-inch bubble chamber has already been exposed to 3.24-BeV/c π^- on hydrogen, yielding 75 rolls of film (45,000 pictures) for the start of "π63." The 4- and 6-pronged interactions are presently being scanned and measured. The reaction $\pi^- + p \rightarrow \pi^-\pi^-\pi^+p$ will be examined for evidence relating to the existence of the first Regge recurrence of the pion in the effective-mass distributions of $\pi^-\pi^-\pi^+$ triplets. Additional film will be taken in the next several months over a large range of momenta (1.5 to 4.2 BeV/c), with special emphasis at $\approx$ 2.0 BeV/c, in order to obtain data on the quantum numbers of the κ (725-MeV $K\pi$ resonance).
(OID, GRK, DM, GAS)

Beam Design

A new K^-, π^- beam has been designed and built in a collaborative project undertaken by the Alvarez and Trilling-Goldhaber groups. The beam will deliver π^- from $\approx$ 2.0 to 4.4 BeV/c and separated K^- from $\approx$ 2.5 to 3.0+ BeV/c to the 72-inch hydrogen bubble chamber. Experimental runs with π^- commenced about March 15 when the Bevatron first returned to operation after completion of the Bevatron improvement program. Between March and June, π^- running will continue, and at the same time additional features of the beam required for K^- separation will be completed and tested. Experimental runs with both K^- and π^- will commence in June and continue for a period of 6 to 7 months.

Usually, K^- are separated by conventional techniques using two stages of electromagnetic separation; however, our beam incorporates a unique optical design involving a new and generally applicable method for compensation

21. Pierre Bastien and J. Peter Berge, Phys. Rev. Letters 10, 189 (1963).

of chromatic effects to increase momentum acceptance. In gist, the optical system is required (in addition to the usual demands) to form stigmatic foci at the mass-resolving slits, which remain stigmatic to a high degree over a relatively wide range of momentum. With momentum dispersion the foci loci are nearly straight lines inclined at a small angle to the nominal beam direction. The mass slits are titled correspondingly with the slit jaws lying on the foci loci. It is expected that nearly perfect chromatic compensation can be effected in this way for a momentum bite of approx 4% without the need for special magnets and without any significant compromise of any other features of the beam.

A total of 50 ft of a parallel-plate separator will be used, 20 ft in the first stage and 30 ft in the second. The separators have glass cathodes and stainless steel anodes of improved design to produce higher and more uniform electric fields. With a 5-cm gap the separators operate satisfactorily in the 500- to 550-kV range, with the field in the central 5 in. wide region uniform to $\approx 0.1\%$.

Refined methods of correction and measurement of the magnetic fields of quadrupole magnets were developed, with the result that effective spurious field components in all such magnets were reduced to $\approx 0.1\%$ of the quadrupole field at a radius of 3 in. Three types of quadrupole magnet defects required correction or compensation: (a) relative rotation of the elements of doublet and triplet sets, (b) the multipole component other than the quadrupole in the main field exclusive of the fringe field, and (c) fringe effects. Relative rotation was reduced to $< 10^{-3}$ radian by careful mechanical alignment. The multipole component of the main field was measured directly by a dynamic sampling method. A sextupole component caused by large-scale asymmetries in the magnetic structure was usually present but was eliminated by relative adjustment of appropriate pairs of the four individual quadrupole coil currents. Octopole and twelve-pole component caused by local pole-tip asymmetry and departure from ideal boundary conditions was reduced by addition of iron rods of appropriate size and distribution symmetry running the length of the magnets along the edges of the pole tips. No other multipole of significance was present at a radius of 3 in. The effects of fringe focusing were compensated in the plane of separation by means of an octopole perturbation at the ends of the magnets produced by the addition of iron of appropriate size and symmetry at the ends of the pole tips.

The precautions taken to reduce optical aberrations are expected to result in an overall effective aberration $\approx 20\%$ of the π-K separation. In the separators in the plane of separation the relative π-K deflection is ≈ 3 to 5×10^{-4} radian.
(JJM, REF, JL, DM, DS, JBS, FS, AR in collaboration with members of the Goldhaber-Trilling group)

DATA REDUCTION

Franckenstein System

The scanning and measuring system for the 72-inch hydrogen bubble chamber is in continual operation, with five measuring projectors (one of which is the converted 15 inch measuring projector) and eleven scanning projectors.

The use of the 15-inch bubble chamber system has been decreasing because there have been no new exposures with this chamber. The system now consists of one measuring projector and one scanning projector. One measuring projector and eight scanning projectors are on loan to other groups in the Laboratory.

Data-Reduction Operations

Personnel (Alvarez Scanning and Measuring Group)

The total effort in full-time equivalents at the beginning of this period (Nov. 1962) was 63; by the end of this period (April 1963) it fell to 55 full-time equivalents.

Scanning

During this 6-month period the bubble chamber film was scanned as follows:

Experiment	Scan	Number of rolls
APE	HiHiPi rescan (π^- in H_2)	88
APE	Eta rescan (π^+ in H_2)	150
APE	Special scatter scan	
	PreXmas film (π^- in H_2)	30
	PostXmas film (π^- in H_2)	95
K72	Scan 1 (K^- in H_2)	
	1.34 BeV/c	1
	1.53 BeV/c	1
	1.63 BeV/c	1
	2-prong scan for spiral reader (1.05 to 1.11 BeV/c)	61
K72	Scan 2 (K^- in H_2)	
	1.34 BeV/c	92
	1.45 BeV/c	63
	1.53 BeV/c	78
	1.63 BeV/c	6
	2-prong scan for SMP (1.22 BeV/c)	108
	2-prong scan for spiral reader (1.05 to 1.11 BeV/c)	24
K72	Scan 3(K^- in H_2) 1.22 BeV/c	55
π72	Scan 1 (π^- in H_2)	40
π72	Scan 2 (π^- in H_2)	286
π72	2-prongs (π^- in H_2)	50
π72	Cross-section scan (π^- in H_2)	125
K72(D_2)	Scan 1(K^- in D_2)	14-1/2
K72(D_2)	Scan 2 (K^- in D_2)	36
Total 72-inch bubble chamber rolls scanned		1405-1/2

Measuring

The following table indicates the measuring activity during the past 6-month period. The table does not include the measuring time spent at the Spiral Reader or the SMP system since the time spent on production measurements during that period is not clearly separable from the effort spent on debugging and testing the systems. At the end of this period, both systems have been using for production measurements approximately 60 hours of measuring time/week.

MP	Bubble chamber	Measuring time (hr)	Instruction time (hr)	No. of events
I D	15 Inch	517	0	2,632
I A	72 Inch	652	30	1,863
II A	72 Inch	2316	114	11,860
II B	72 Inch	2979	46	22,340
II C	72 Inch	2662	30	14,806
II D	72 Inch	2529	169	14,709
Total		11,655	389	68,210

The SMP (Scanning and Measuring Projector) System

General

During this report period the SMP has become operational. Three SMP tables have been constructed and used to measure two-prong events from the 1.22-BeV/c K^- film of the K72 experiment. One of the three tables has been sent to the University of Illinois and is operating with their 7090 computer. A test of a sample of 120 elastic scattering events taken from a sample of 360 two-prong measurements has been studied. This study indicates there are no serious systematic biases in the measurements. The precision of individual "smooth" points derived at the filtering stage is great enough that the scatter of points about fitted curves is the same as for events measured on Franckensteins.

Program Developments

Executive Program

The dialogue portion and the interruptible portion of the executive program were debugged to the extent that program flow was possible in the early part of this period. Much work has been done to incorporate features that either improve communications with the SMP operators or decrease the computer time and increase the reliability of measurements; for example: (a) The filtering routines for fiducial measurements, track measurements, vertex measurements, and end-point measurements have all been converted from FORTRAN programs to machine language programs. All arithmetic operations were changed from floating point to fixed point at this time, thus eliminating conversion from fixed to floating point on each ingested point. We estimate that this speeded the filtering by at least a factor of two. (b) The program was enlarged to accept indicative PANAL information from a tape made by the Alvarez Library system LINGO (the program that makes this tape is called SMPP). This allows the operating SMP to be used with a

minimum amount of typewriter to 709 dialogue. With this modification we will measure approximately 10,000 two-prong events in the K72 film as the first full-scale experiment with the SMP system.

Testing Routines

The typewriter test program has been modified to include testing of commands to the SMP used to change views.

A new overall test program is under development. It works simultaneously with all SMP's and incorporates two separate programs. The first of these is a typewriter test program which types out on command the characters as they have been received from an SMP; the second one converts the coordinates of the data points from an SMP to a two-dimensional histogram and reconstructs this histogram on the typewriter, using numbers and letters to represent frequencies. Both of these parts have been separately debugged and will be combined in the near future.

Event Analysis Programs

Some program-development has been done on new routines to test the SMP data through the kinematics stage. After these routines are operational, they will be included in the executive program to increase the reliability of the output data.

The routine VTEST is to make three tests on three-constraint "V" events. The program tests coplanarity, conservation of transverse momentum, and conservation of energy by using a χ^2 criterion. The program has been tested by comparison with the results of PACKAGE for a sample of single "V" events from the K72 experiment. The test indicates that the method is reliable in from 97 to 99% of the cases. Another program has been written that will generate the hypotheses (mass assignments) for a given topology which satisfy conservation laws that can be specified.

Spiral Reader

General

The spiral reader is at present measuring 2-prong events from the 1.1-BeV/c film of the K-72 experiment. However, developmental work and maintenance are still occupying a large fraction of the time.

At present about 85% of the events measured on the spiral reader are being processed satisfactorily by the entire system. Ten percent of the events fail because of operator errors; the remaining 5% fail owing to difficulties in either the spiral reader or the filter program. Efforts are continuing on both the spiral reader and the filter program to reduce the failures from these sources.

Instrument Development

Three improvements are being worked on in order to reduce the spiral reader's measuring time per event.

First, the spiral reader's control sequence is being changed to take advantage of the fact that the three views can now be measured without changing the film's position.

Second, to eliminate some of the interruptions in the measuring sequence, modifications are being made in the logic that controls the writing of the data on the magnetic tape.

The third change is necessary because an x-y measurement is made at the end of each track and is used by the filter program to select the correct tracks and by the PACKAGE program to correlate the tracks in the three views. The modification, which is being developed, will speed the measurement of these x-y points.

The three modifications mentioned above should reduce the measuring rate from the present 5 minutes per event to about 3 minutes per event.

Program Development

The spiral reader modifications, described above, will produce changes in the format of its output data. To enable the filter program to process this new data format, some sections of the program are being rewritten. Additionally, these sections are being improved so that future changes in the data format can be handled with only slight changes in the filter program. Several modifications are planned in the method used by the filter program to find the tracks; these modifications should reduce the number of events that fail as a result of the filter program, and also reduce the dependence of the filter program on the x-y measurements on the individual tracks.

QUEST Program

The QUEST program has been completely coded for the IBM 709 system. Since the preceding report a few new routines have been added to make semiproduction processing possible. These routines allow a previously entered processing sequence to be repeated at machine speed with no new entered information and with little or no output information. For those events of which there are two or more of the same type, the QUESTing has been speeded up greatly. An event processed in this manner requires approximately 30 seconds to complete. Another new routine allows the operator to do a missing mass calculation with the incident track missing.

QUEST is now being converted to a 7090 program so that we may be ready for a change in computers when it is necessary.

During the past 6-month period, the QUEST running time has averaged approximately 13 hours per week, with 25% of the running time being utilized for debugging purposes (both electronic and program), 60% as useful physics output, and 15% as IBM 709 down time. The useful output time has been proportioned $\approx$ 70% for K72 experiment, and $\approx$ 30% for the APE experiment; 53% of the useful time has been spent on Ξ^- events, 27% on leptonic decays, and 20% on zoons.

The QUEST system has been described in a published article.[22]

PROGRAMMING EFFORTS

Personnel

The programming work described below has been done by Robert J. Harvey (in charge of the Programming Group), Benjamin Abington, Jim Baldridge, Lynn Champomier, Barbara Cottrell, Orin Dahl, Cecil Draper, Larry Drews, Bill Graziano, Mark Horovitz, Marge Hutchinson, Daphne Innes, Dave Johnson, Ralph Jones, Max Leavitt, Mary Beth Lieberknecht, Jack Merkin, John Munson, Bart Nyman, Barrie Pardoe, Sam Penny, Jed Rice, Rudy Savala, John Shafer, Jon Stedman, and Tom Tonisson.

General Information

The main body of programs used by the Alvarez Hydrogen Bubble Chamber Data Analysis System has been described in previous semiannual reports. For the purposes of review we briefly enumerate the main functions of these routines. PANAL operates on the output from the measuring projectors and performs checks on these measurements to eliminate obvious errors. PACKAGE does the geometrical reconstruction of the tracks measured as well as kinematical fitting of the events to various hypotheses. EXAMIN reduces the PACKAGE output to physically interesting quantities (invariant masses, decay angles, etc.). SUMX plots the final data in one- and two-dimensional histograms, scatter plots, etc. Finally, LINGO is an overall library program which keeps record of the events through all stages of the scanning and measuring process.

The improvements made on the existing systems as well as new programs written during this past 6-month period are enumerated below. In addition, a large amount of effort went into programming directly associated with the development of new instrumentation. For the purpose of better coherence, that work is described in the preceding section together with the hardware involved in those instruments.

PANAL Program

The data-editing program PANAL[23] has been extensively used as part of the Alvarez Group data analysis system. The logically independent parts of PANAL have been separated into essentially separate programs, each of which may be run independently. The PANAL write-up has been updated and revised.

PACKAGE System

The PACKAGE III system is being used in the analysis of all 72-inch bubble chamber experiments done by this group. Various minor changes have been made to PACKAGE and a few old errors have been found and

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22. Margaret H. Alston, James E. Braley, and Peter White, Rev. Sci. Instr. 34, 64 (1963).

23. M. H. Alston, J. P. Berge, et al., PANAL, Alvarez Physics Note No. 358, November 30, 1961; revised February, 1963.

corrected. One now has the option of measuring any track in an event either in two views or in all three views. Neutral tracks may be measured or left for the program to reconstruct. An attempt is now made to salvage events that would otherwise be rejected because of difficulties encountered when a track is measured farther in one view than in another view.

A compressed version of PACKAGE was provided for incorporation into the SMP system.

The new three-view-geometry program "TVGP" is approximately one-half completed, and sections are being tested by use of simulated input data.

LINGO Operation

LINGO I[24] has continued in production status with few changes. Three new operations have been incorporated, one has been extended, and the overall operation of the system has been improved.

The new operations are CANCAN (for comparing scan cards from different scans), CONFLICT (for comparing master lists from different scans), and X1 (for producing special tallies by roll number).

The MODIFY operation has been extended to allow for the placing of scanner conflict results on the master list.

The system has been modified to achieve easier and more efficient operation on the computer.

A special program SMPP has been written. This program will furnish the SMP's with scanning information from the master list library.

SELEKT Program[25]

SELEKT is designed to select arbitrary subsets of events from PANAL output tapes and transfer these events to other tapes, conserving the PANAL output format. A list of indicative data on the selected events is also provided. This program is presently in operation.

SUMX Program[26]

Miscellaneous changes and additions were made to the SUMX program. A supplementary write-up of SUMX, intended for programmers wishing to code their own SUMX subroutines, has been completed.

24. Samuel Penny, LINGO Systems, Memo Alvarez Programming Note P-7, January 4, 1962; Operating Instructions for LINGO I, Alvarez Programming Note P-8, Sept. 11, 1962.

25. Laurance Drews and Samuel Penny, SELEKT (from PANAL output), Alvarez Programming Note P-26, January 29, 1963.

26. Lynn Champomier, SUMX, Alvarez Physics Note No. 389, June 21, 1962.

A new input-output system is being incorporated into SUMX. This improvement will provide (a) automatic assignment of scratch tapes, (b) ease of modification for use at other 709-7090 installations, and (c) vastly superior buffering features.

GENIE System

This EXAMIN-type system (previously called EXAMW[27]) has been incorporated into the set of data analysis routines to be used for the $\pi 63$ and K63 experiments.

PHASE SPACE Programs[28]

Further additions and modifications have been made to this set of programs to extend their range of application. Work has begun to consolidate several of these programs (H4, H5, H6, and part of ATHOS) into one general routine.

Miscellaneous

A 7090 subroutine MAGPIE was written to compute coefficients of polynomial approximations to the magnetic field components for the 72-inch hydrogen bubble chamber. MAGPIE is used as a subroutine of MINFUN. The purpose of this work is to try to get a better approximation to the magnetic field for incorporation into the standard data analysis routines.

A Study of Random-Number Generators

It was noticed that the standard LRL random-number generating routine, RAN(F), did not produce uniformly distributed sequences in certain cases in which it was used to generate vectors for Monte Carlo calculations. The causes of this trouble are now understood. Several subroutines to replace RAN(F) have been written. These routines give uniformly distributed vectors for the applications in which the trouble was noticed. A collection of routines for testing properties of statistical distributions have been created--some written at LRL Berkeley, some obtained from elsewhere.

Our conclusions are:

(a) No one random-number generator is best for all applications.

(b) In Monte Carlo calculations, it is important to be aware of the way in which nonrandom sequences can arise.

(c) A set of test programs is useful for checking distributions.

(This work was done in cooperation with personnel from Math and Computing and the Segrè Group.)

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27. D. Johnson, WRING and EXAMW, Alvarez Programming Note P-5, August 31, 1962.

28. Marcus Horovitz, A Summary of Available Programs for Calculating Phase-Space Distributions, Alvarez Physics Note No. 392, May 23, 1963 (see also Alvarez Physics Notes Nos. 393 through 397).

Work Done for Other Groups

The following work was performed for groups at UCLRL Berkeley other than the Alvarez Physics Group.

BONUS Program

A 7090 program, BONUS, was written to compute angular and momentum distributions for two-body interactions. In this program the target particles are not assumed to be at rest, for they have a specified momentum distribution. Experimentally determined cross-section data are used in the calculations. (Mark Horovitz for the Segrè-Chamberlain Group)

TAILOR Program

A program for fitting models to experimental data was also written. Several versions of the program 9B20 (written by M. Berman of the National Institute of Health) have been tested and are being applied to

(a) analysis of the kinetics of tracer iron in the blood of human subjects, and

(b) determination of parameters of radiation survival curves.

(Mark Horovitz for Myron Pollycove and Jo Lyman from Donner Laboratory)

A library program for use in data processing of physiological and medical data has been constructed.[29] For demonstration purposes it has been run successfully with simulated input data. The scheme is flexible and can accept a wide variety of data formats.

AGE Study

A UCRL report describing the status of this study of the aging process in human populations is being prepared.[30] (Mark Horovitz for Roger Wallace)

Expediting System

The expediting system is involved in three major areas of work: expediting, key punching, and magnet tape manipulations. In the past six months, several innovations have been introduced to enhance operating efficiency in each of the areas. These include

(a) The establishment of a program card file at the computer to facilitate the maintenance of records relating to machine time used.

(b) Inauguration of staggered shifts for key-punch operators so as to maintain key-punch services for 10 hours per day, Monday through Saturday.

(c) Coordinating the expediting services so that now, in some cases, a single expediter services several groups or experiments.

(d) Utilizing key-punch personnel to assist in debug-expediting and thereby facilitating the overall coverage in this area.

(e) Introducing tape labels of different colors to differentiate the bits per inch (BPI) densities of magnetic tapes.

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29. Physics Division Semiannual Report, UCRL-10572, November 1962, p. 74 (BAYOU, paragraph b).

30. Physics Division Semiannual Report, UCRL-10572, November 1962, p. 75.

During the period, a comprehensive survey was made of various aspects of magnetic tape manipulations at the Laboratory. Included were the procurement, handling, storage, and maintenance of magnetic tapes. Studies in this area were also made of facilities at several other installations, including LRL Livermore, Lockheed, and Standard Oil. The results of the survey were compiled in a memorandum, and at present the group is in the process of implementing many of the recommended proposals.

BUBBLE CHAMBER OPERATION AND DEVELOPMENT

72-Inch Chamber Operations

On November 1, 1962 the 72-inch chamber was in the process of being overhauled and some small changes were being made in the chamber circuits. During the first part of the report period the chamber magnet was walked to the position required for the K63 experiment. All the external plumbing was installed and tested by the end of January 1963. The chamber was installed in the magnet during the first weeks of February and the bubble chamber was ready to start cooldown. On March 11 cooldown commenced, and the chamber was operational by March 20. Between March 20 and the present 160 rolls of film have been taken in the 3.2-BeV π^- beam.

The 72-inch bubble chamber group also worked on spectrometers during the period from November 1 to February 15 and successfully completed two 10-ft spectrometers and one precision 20-ft spectrometer. The group made 50 glass cathode segments and was instrumental in the design and construction of a new precision 20-ft anode--bubble chamber crew people assembled and tested all the spectrometers now in use by the Powell-Birge group and the Alvarez group.

In January of 1963 a new ultrahigh-vacuum high-voltage test device was recieved and several bubble chamber operations people put effort into rebuilding two high-voltage power supplies needed for test purposes. This work is being continued and the high-voltage device should be tried in a few weeks.

The 72-inch bubble chamber is in operation at present, and with the exception of a small vacuum leak is doing well. Before deuterium can be used in the chamber a 2-week shutdown will be required to patch the leak. We plan to schedule this repair at a time that will cause the least inconvenience.

25-Inch Chamber Development

The tests of the expansion bellows have been completed successfully. As described in the previous semiannual report, the difficulties encountered in fabrication of the bellows were solved by changing both the material used and techniques used in welding the bellows halves together. A test pair of bellows survived 3.3 million pulses with no failure at twice the normal operating stroke.

The stainless steel castings for the chamber body and window flanges have been machined after some delay due to a shop load of priority jobs. The expansion bellows is being welded to the halves of the chamber. The inflatable gaskets for sealing the chamber windows are being fabricated.

The piping connections between the control panel and the chamber top plate have been completed. The main insulating high-vacuum system has been operated in the course of testing the liquid nitrogen heat shield. The refrigeration system (removed from the "retired" 15-inch bubble chamber) is being modified.

As indicated in the preceding report, six coils for the magnet were promised by the end of November 1962, and the remaining six coils were promised by the first of the year (1963). The supplier, Westinghouse Electric Corporation, has not delivered any coils as of this date and is some 6 months behind the original delivery date.

The chamber condenser and precision windows have been fabricated, fiducial marks applied and measured, and the whole thing shipped to Liberty Mirrors Div., L-O-F Glass, for application of antireflection coatings. The aspheric condenser lens is nearing completion at Tinsley Labs. Design effort is continuing on the camera, with detailing of the final components nearing completion. The mechanical shops are currently processing job orders covering several of these components. Control components for the camera film-drive unit are complete and under test. Engineering design for the data display panel is under way.

Because we have experienced delays due to shop priority, shortage of engineering help, man hours lost in assisting the contractor with magnet coil and bellows development, the engineering run should be conducted in August 1963.

PHYSICS RESEARCH

Walter H. Barkas in charge

STRANGE-PARTICLE RESEARCH

Energy-Momentum Balance in the Reactions $K^- + p \rightarrow \Sigma^{\pm} + \pi^{\mp}$

John N. Dyer, Walter H. Barkas, and Harry H. Heckman

The anomaly in the momentum balance of $K^- + p \rightarrow \Sigma^- + \pi^+$ [Bull. Am. Phys. Soc. 5, 224 (April 25, 1960)] has been studied exhaustively, and the conclusion reached is that it must be attributed to a new physical effect: the energy-loss rate of a negative particle is less than that of a positive particle at the same velocity. The experimental results and the theory are being prepared for publication. A result of this investigation is that it raises our estimates of the masses of the Σ^- and Σ^0 hyperons.

K^--Meson Reactions in Complex Nuclei

Investigation of Y_0^* (1405) Production

Angela Barbaro-Galtieri, Frances M. Smith, and Jack W. Patrick

The investigation of Y_0^* (1405) production by K^- mesons at rest in emulsion, referred to in the preceding semiannual report, has now been concluded and the results submitted for publication. Some 270 events of $\Sigma\pi$ production by K^- mesons at rest were analyzed. The invariant mass and the momentum of the $\Sigma\pi$ system were calculated, as well as the appropriate errors for events meeting the criteria of capture by C^{12}. A sample of events was, in addition, subjected to analysis to determine the effect of distortion on the angle measurements. No significant effect was found.

The $\Sigma\pi$ mass spectrum obtained for K^- interactions in C^{12} shows prominent enhancement in the region around 1411 MeV with a width of about 20 MeV. This is not necessarily a resonance effect, because it can be explained by an impulse model of direct $\Sigma\pi$ production. A Y_0^* (1405) resonance of 1 MeV width was not confirmed.

Mechanism of Hyperfragment Production

Jack W. Patrick and Piyare L. Jain

The mechanism of hyperfragment formation in K^- captures at rest in emulsion nuclei has been investigated.

A sample of 55 parent stars of hyperfragment production has been studied along with the decays, in an attempt to understand the production mechanism. Several criteria were used to separate the K^- captures in C, N, O from Ag and Br. The momentum spectra for different hypernuclear species are given and are compared with the momentum spectra of free Λ's from helium bubble chamber experiments.

Results from the energy spectra of the pions emitted in the K^--capture stars indicate a distribution into two separate groups, the lower-energy group being larger. These events correspond presumably to a Σ-hyperon intermediate particle in the Λ production.

It is also indicated that most of the two-nucleon absorptions take place in heavy nuclei.

Multinucleon K^--Capture Mechanism

Jack W. Patrick, Harry H. Heckman, William Z. Osborne, and Walter H. Barkas

Data have been gathered on some additional 37-MeV events which indicate multinucleon capture of the K^- meson. This brings our total number of analyzed events to some 67 of the type

$$K^- + (np) \rightarrow \Sigma^- + p,$$

where the kinetic energies of the Σ and p are greater than 60 and 30 MeV, respectively.

The precision of the calculation of the invariant mass of the Σp system is sensitive to the angles involved; therefore, the analysis must be dependent on the speed with which very accurate (and tedious) dip measurements can be made. This analysis is now about three-fourths done.

SPACE RESEARCH

East-West Asymmetry in the Flux of Geomagnetically Trapped Protons

Harry H. Heckman
(with George H. Nakano, Lockheed Missiles and Space Company, Palo Alto, Calif.)

The analysis of a set of four emulsion packets carried aboard an oriented polar-orbiting satellite, recovered on September 1, 1962, has been completed. The results of the analysis are:

(a) More than 90% of all stopping particles are protons whose origin is the Van Allen radiation belt. The protons were detected in the South Atlantic anomaly at an altitude of about 364 km.

(b) The geomagnetically trapped protons were detected near their mirror points in a highly localized region of space. As a consequence, the protons were confined to a plane whose pitch angle distribution is observed to be Gaussian with a standard deviation $\sigma \approx 7.4°$.

(c) An east-west asymmetry in the flux of geomagnetically trapped protons was observed, confirming an effect predicted by Lenchek and Singer.[1] From measurements of the asymmetry for 60-, 107-, and 116-MeV protons, we obtained a value of 62.0 ± 5.0 km for the scale height of the atmosphere at 364 km altitude. This result is in good agreement with measurements of atmospheric scale heights deduced from observations of satellite drag.

1. A. M. Lenchek and F. S. Singer, J. Geophys. Res. 67, 4073 (1962).

An article on this work has been published in J. Geophys. Research 68, 2117-2120 (1963).

Energy and Angular Distributions of Trapped Protons in the South Atlantic Anomaly

Harry H. Heckman
(with George H. Nakano, Lockheed Missiles and Space Company, Palo Alto, Calif.)

We have measured the differential energy spectrum and angular distributions of mirroring protons at ≈400 km altitude in the region of the South Atlantic magnetic anomaly for energies between 60 and 140 MeV. These measurements have been obtained from emulsion detectors recovered from three polar-orbiting satellites during September, November, and December 1962. The altitudes at which these measurements were taken are between 364 and 419 km. The spectra are qualitatively the same for each flight, although there is some indication that the spectral shape or flux or both may depend on time as well as altitude. The omnidirectional flux at 60 MeV observed in September 1962 was $2.0 \pm 0.2 \times 10^4$ cm^{-2} MeV^{-1}. The curve was consistent with a flat spectrum between 60 and 130 MeV.

From a detailed analysis of the pitch-angle distribution of the mirroring protons as a function of incident direction of the proton, and using a theoretical estimate of the intrinsic pitch-angle distribution, we have deduced the approximate geographic area over which the particles were detected. The data-acquisition time is thereby estimated to be about 10^3 sec, and the mean flux at 60 MeV is approx 20 protons cm^{-2} MeV^{-1} sec^{-1}.

Work will continue in order to extend these spectrum measurements to higher energies, and to investigate how the spectrum changes with altitude and time.

HEAVY-ION RESEARCH

Neutrons Produced in Heavy-Ion Reactions

William G. Simon

The results of this program were reported at the Stanford meeting of the American Physical Society [Bull. Am. Phys. Soc. 7, 604 (Dec. 27, 1962)] and at the 3rd Conference on Reactions Between Complex Nuclei (see UCRL-10689), the proceedings of which are to be published by University of California Press. Energy and angular distributions of the neutrons in the center-of-mass system were calculated. The anisotropy [ratio of $\sigma_{forward}$ to σ_{90^0}] is about 2 at 1.5 MeV and decreases to a nearly flat distribution above 6 MeV. Calculations of the distribution of neutrons from postfission evaporation lead to the suggestion that some neutrons are evaporated prior to fission, and thus shed light on the interesting and elusive problem of fission-neutron competition.

Multiple Scattering of Heavy Ions

The list of targets and projectiles for which multiple scattering has been measured now includes O^{16} ions on Al (thick), Au (thick and thin), zapon (thick), Ni (thick), and Pd (thin), and A^{40} ions on zapon (thick), Al (thick), and Au (thin). "Thin" refers to targets that are not thick enough for Molière's theory to be applicable, and "thick" to targets for which Molière's theory is supposed to hold. This theory describes the scattering well in all cases in which it should.

Charged-Particle Production in O^{16} Interactions

Donald V. Reames

A preliminary report of the magnetic analysis of light charged particles produced at 0 deg in the interaction of 167-MeV O^{16} ions with Al, Ni, Ag, and Au targets is in preparation, as UCRL-10693 and will be published in the Proceedings of the Third Conference on the Reactions Between Complex Nuclei (University of California Press). The experimental yields are compared with calculations of multiple particle emission based on the statistical model, and are often found to be in disagreement. The discrepancy can, in some cases, be ascribed to the production of particles by direct or grazing mechanisms. Further calculations, which include the effects of angular momentum and fission, are in progress.

CALCULATION OF IONIZATION INTENSITY CONTOURS

Douglas Greiner and Walter H. Barkas

Calculations of the ionization energy density in biological material (or other absorbers) traversed by a beam of charged particles is complicated by the angular divergence of the beam and by straggling and scattering, as well as by particle decay and nuclear interactions in flight and at the end of the particle range. The ionization-range relationship, the beam size, and the momentum bite are also input parameters. The problem has been reduced as much as possible by dimensional arguments, and an IBM 7090 program "LEOCLI" has been written to calculate the energy density per unit volume (rads/cm^3) dissipated by a uniform beam of arbitrary circular cross section of any kind of heavy charged particle of any energy confined to an arbitrary momentum interval. Minor changes in the program suffice to vary the input conditions.

PHYSICS RESEARCH

Kenneth M. Crowe in charge

MESIC x-RAY STUDIES

Alan Astbury and Robert Shafer

A precision 7.7-m bent-crystal spectrometer has been placed in operation with a 200 × 200 × 6-mm quartz crystal at the 184-inch cyclotron for use in mesic x-ray studies. A cyclotron run in January yielded data on π-mesic-signal and background counting rates. As a result of this, equipment is now being prepared for a full-scale measurement later this year.

The successful completion of this research program will yield

(a) direct measurement of pion mass,
(b) more precise knowledge of vacuum polarization effects in mesic atoms, and
(c) measurement of level shifts resulting from strong interactions.

$\mu^{\pm}$ DECAY SPECTRA

Alan Astbury and Philip Beilin

In August 1962 an experiment was carried out at the 184-inch cyclotron to determine the Michel ρ parameter. The experimental technique consisted of stopping positive muons in a lithium target and observing the positron decay spectrum with a 180° n = 1/2 spectrometer.

In November 1962 the above technique was used to study the decay spectra of both positive and negative muons stopping in a copper target. The added purpose of this run was to compare the shape of the observed bound negative decay spectrum with theoretical predictions.

Since the completion of the November run, analysis of the experimental data of the above two runs has been in progress.

K^+ DECAY SPECTRA

Robert Beck and Roy P. Haddock

In June through July 1961 this group carried out the first phase of an experiment on the K^+ decay spectra. Since the data from this first run are still being analyzed, the following discussion of data is necessarily tentative and incomplete. We expect to take some 10,000 useful K^+ events from our data, but as our selection criteria are still only tentative, this number could change by 2000 either way. First of all, we expect to clarify the $K_{\mu 2}/K_{\pi 2}$ relative branching ratio. Some recent xenon bubble chamber data by Trilling et al., give

$$K_{\mu 2}/K_{\pi 2} = 3.45 \pm 0.18,$$

while the emulsion data of Alexander give

$$K_{\mu 2}/K_{\pi 2} = 2.44 \pm 0.26,$$

and Boyarski et al., report

$$K_{\mu 2}/K_{\pi 2} = 2.98 \pm 0.25.$$

We expect to determine their ratio to 5%. A preliminary estimate of $K_{\mu 2}/K_{\pi 2}$ has been made on the basis of 698 events. We find a value of

$$K_{\mu 2}/K_{\pi 2} = 2.1.$$

If only statistical errors entered into this fit, the error would be 2.1 ± 0.2, but in view of the approximate nature of the corrections made in the experimental data, a good estimate of the error on this branching ratio cannot be given as yet.

We expect approximately 300 events in the $K_{\mu 3}$ spectrum (KE of $\mu^+ > 30$ MeV). These data will provide an estimate (assuming constant form factors) of g_V/f_V for the muon.

We will also obtain the electron energy spectrum from Ke_3 decay (we expect approx 300 events in the upper 2/3 of the spectrum). Present knowledge of this spectrum is based on emulsion data (some 50 events), which do not agree well with theory.

184-INCH CYCLOTRON BEAM STACKING STUDY

Kenneth M. Crowe and Ned Dairiki

Preliminary investigation has been initiated on the possibility of increasing the beam intensity of the 184-inch synchrocyclotron by the use of an auxiliary central dee. A beam stacking procedure has been proposed and computer studies are presently in progress.

THEORETICAL GROUP

David L. Judd

FOUNDATION OF THE THEORY OF THE SCATTERING MATRIX

From proposed axioms, several theorems essential to the development of S-matrix theory have been proved. Though perhaps trivial sounding they are not so trivially proved. Some results are these: The S matrix defined by the superposition postulate is unitary. The usual connection between spins and representations of the rotation group follows from the postulate concerning observables. The invariance of M functions (certain parts of the S matrix) under the real (restricted) Lorentz group follows from the postulated relativistic invariance of observed phenomena. The invariance of M functions under the real (restricted) Lorentz group implies that if M is an analytic function at any point in the physical region then the analytic extension from the neighborhood of this point leads to a function defined over a multisheeted manifold in which each sheet is mapped into itself by a (proper) complex Lorentz transformation and the function on that sheet is invariant under (proper) complex Lorentz transformations (100 pages of proof). These results clear the way for a systematic study of the combination of the requirements of unitarity, analyticity, and Lorentz invariance. (Henry P. Stapp)

Work has continued on the classification with respect to C, P, and T properties of holomorphic scalar amplitudes for the scattering of nonzero-mass particles with arbitrary spins. New results by K. Hepp[1] on the general construction of amplitudes without kinematical singularities are being used. Study of the general properties of covariant holomorphic functions of several four-vectors has also continued. In particular, it has been shown that a holomorphic function of several four-vectors covariant under the real homogeneous Lorentz group has an analytic continuation by means of complex Lorentz transformations from the neighborhood of any point where the Gram determinant of the vectors has a rank of two or greater, and that such a function is locally covariant under the the complex Lorentz group at such points. Stapp has given a general proof that removes the restriction that the rank be two or greater.[2] (David Williams)

It is shown that the derivative of the S matrix with respect to momentum transfer defines an "impact parameter," which coincides in the semiclassical limit with the usual impact parameter of classical theory. This, along with the definition of time duration,[3] provides a dynamical principle and means for constructing trajectories in the semiclassical limit.

V. N. Gribov and Ya. Pomeranchuk have argued that there must be an essential singularity in the partial wave amplitude for elastic scattering when

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1. K. Hepp (Eidgenössische Technische Hochschule, Zürich) Helv. Phys. Acta (to be published).

2. Henry P. Stapp, private communication.

3. M. L. Goldberger and K. M. Watson, Phys. Rev. 127, 2284 (1962).

$\ell = -1$, provided it is given by the Mandelstam representation.[4] Following Bethe and Kinoshita,[5] we have examined the problem of Regge poles at high energy, using the Schroedinger equation. Two cases have been considered; the first is that of a local potential representable as a sum of Yukawa potentials, the second is a potential which reproduces in Born approximation the nonrelativistic reduction of that part of the scattering amplitude proportional to the third Mandelstam double spectral function, and is nonlocal in character. A study of the solutions of the Schroedinger equation at high energy shows that in the first case there is a single pole in the vicinity of $\ell = -1$, while in the second there are an infinite number that accumulate at $\ell = -1$ and so yield an essential singularity in the partial-wave amplitude at that point. (Joseph V. Lepore and Robert J. Riddell, Jr.)

Analytic properties of scattering amplitudes involving two- and three-particle states have been studied; singularities in the unphysical sheets reached by continuation across the inelastic section of the unitarity cut have been determined. It is found that the branch cut associated with a process that corresponds to the isobar mechanism of Peierls is located at such a position in an unphysical sheet that it cannot directly enhance the scattering amplitudes in the physical region; however, for a state involving suitable dynamical forces, a resonance pole can arise in another unphysical sheet that can be reached directly from the physical region and is indeed responsible for an observable resonance. A summary of this investigation has been given in a paper titled "Singularities in the Unphysical Sheets and the Isobar Model," which will be published in The Physical Review (June 15, 1963). (Rudolph C. Hwa)

A program has been initiated to generalize the unitarity condition in such a way that <u>all</u> singularities of a given amplitude associated with whichever channel can be obtained from a generalized unitarity relation written for one channel only. This requires carefully incorporating multiparticle amplitudes into the consideration. By using the generalized unitarity relation, an integral equation is derived, on the basis of which a production amplitude can be expanded in terms of the elastic scattering amplitudes. It is hoped that a clearer understanding of the analytic properties of the production amplitudes can be obtained by first making this unitarity expansion and then continuing into the complex plane. (Rudolph C. Hwa)

There is no statement in the literature as to the uniqueness, in principle, of the phase shifts obtained in the partial-wave decomposition of a nonrelativistic scattering amplitude. Aside from trivial ambiguities in overall sign and definition up to modulo 2π, it seems to be assumed that an angular distribution experiment that measures the modulus of the scattering amplitude will determine the phase shifts uniquely. This assumption has been shown to be invalid by giving a counterexample. For the case of three nonvanishing

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4. V. N. Gribov and Ya. Pomeranchuk, Proc. Intern. Conf. High Energy Physics, 1962; p. 522.

5. H. A. Bethe and T. Kinoshita, Phys. Rev. <u>128</u>, 1418 (1962).

phase shifts, there exists an infinite number of nontrivial ambiguities, in one-to-one correspondence with the values assumed by the S-wave phase shift, which cannot be resolved by arbitrarily precise angular distribution measurements at a fixed energy. Because of the limited nature of this ambiguity, its existence does not seem to have important experimental consequences, and of course the existence of ambiguities with larger numbers of phase shifts has not been shown. Nevertheless, this is an example in which the relative phases of different terms in the S matrix cannot be determined, even in principle. (James Crichton)

Attempts are being made to incorporate the concept of the roughly local nature of interactions into a rigorous S-matrix theory. This concept, implicitly assumed in all microscopic physics, does not seem to have been put on a formal basis, nor has it been exploited in determining properties of the S matrix. The initial work is being done on a certain expansion (a "cluster decomposition") of the S matrix in which the terms are given by tempered distributions free from certain δ functions. (James Crichton and Eyvind Wichmann)

The formulation of crossing symmetry for arbitrary processes is being studied within the framework of the S-matrix dynamical formalism. (Mark Sharefkin)

The possibility that field theory does not unambiguously predict particle-antiparticle intrinsic parities is being considered;[6] relevant data may be available from the Alvarez Group on the $K\bar{K}$ system. (Mark Sharefkin)

In sone current theories of elementary-particle interactions, the elastic two-particle scattering amplitude on the second Reimann sheet of $\sqrt{s-4m^2}$, $\phi^{(2)}(s, \cos\theta)$, possesses singularities dense everywhere on the real negative s axis for arbitrary complex $\cos\theta$. The real negative s axis is therefore a natural boundary of $\phi^{(2)}(s, \cos\theta)$ for arbitrary $\cos\theta$, whereas the partial-wave amplitude $\phi_\ell^{(2)}(s)$ is known not to possess this natural boundary. Inspection of the integral defining $\phi_\ell^{(2)}(s)$ in terms of $\phi^{(2)}(s, \cos\theta)$ might lead one to expect $\phi_\ell^{(2)}(s)$ to possess the same singularities as $\phi^{(2)}(s, \cos\theta = \pm 1)$. It is demonstrated[7] why $\phi_\ell^{(2)}(s)$ does not possess the "expected" singularities. (Jack Wong)

PARTICLE PHYSICS AT HIGH ENERGIES

The theory of nucleon-nucleon scattering previously developed[8-10] was used to calculate the phase parameters as a function of energy in the 10-to-400-MeV region. The theory, based on the Cini-Fubini approach to the

6. Eyvind Wichmann (private communication).
7. Jack Wong, On the Natural Boundary of the Scattering Amplitude (thesis), UCRL-10615, December 1962 (unpublished).
8. D. Amati, E. Leader, and B. Vitale, Nuovo Cimento 17, 68 (1960).
9. Ibid., 18, 409 (1960).
10. Ibid., 18, 458 (1960).

Mandelstam representation, takes into account the effect of 2π exchange both via the resonant p wave (or ρ meson) and via the general uncorrelated exchange of the pions in any angular momentum state. The latter is found to contribute significantly to the scattering amplitude. The possible effect of ω-meson exchange was included. The phase parameters for $\ell \geq 2$ were compared with experiment, and yielded encouraging results. This work appears in Phys. Rev. 130, 750 (April, 1963). Attempts are also being made to reformulate the problem in terms of more suitable scalar amplitudes for the πN problem. It is felt that some of the ambiguity in the analytic continuation of the usual A and B amplitudes can be removed. (Elliot Leader)

Work was continued on the theory of Compton scattering on nucleons[11] in which it is hoped to isolate the effect of the $\pi\pi$ s-wave contribution. The recent classification of the η meson as a +G parity π^0 indicates the necessity of including its contribution to the Compton amplitude. An extremely accurate analysis of photoproduction data[12] is used to calculate the right-hand cut contributions, and the sign of the π^0 contribution——which has been a cause of some controversy——is, we believe, finally settled. The numerical work involved is extremely complicated and difficult to check. However, it is hoped that reliable results will be available shortly. (Elliot Leader)

Work on Regge poles and on high-energy behavior of cross sections has been in progress. It has been shown that the shrinking of an elastic diffraction peak follows in an extremely trivial way from the increase of total cross sections. The results of Martin,[13] valid for the width of the square of the imaginary part of the amplitude only, have been shown to hold for the width of the differential cross section as well. This work will appear in Phys. Letters 15 May, 1963. (Elliot Leader)

The nonshrinking of the pion-nucleon diffraction peak at high energies is being investigated in collaboration with W. Rarita. We are following a suggestion of Chew's that the nonshrinking is a result of a helicity-flip contribution that increases with energy and that cancels the expected shrinking from the helicity nonflip amplitude. The contribution of ρ exchange is being fitted to nucleon electromagnetic structure data and the total cross-section difference. It is expected that the sizable ρ contribution to the helicity flip amplitude should allow prediction of a significant amount of polarization in pion-nucleon scattering at moderately high energies (5 to 10 BeV). (Vigdor Teplitz)

A new formula for a single Regge pole term has been deduced which produces correct analyticity in momentum transfer while retaining the correct behavior in the asymptotic region of the crossed channel and near the pole.[14] A computer program has been devised, for calculating the kernel function of the new Chew equations,[15] which includes the effect of a crossed-channel

11. A. C. Hearn and Elliot Leader, Phys. Rev. 126, 789 (1962).
12. M. Gourdin and P. Salin, University of Bordeaux preprint TB-15, Bordeaux, France.
13. A. Martin, Phys. Rev. 129, 1432 (1963).
14. C. Edward Jones, Analyticity of Regge Pole Terms, UCRL-10700, February 26, 1963 (submitted to Phys. Rev.)
15. Geoffrey F. Chew, Phys. Rev. 129, 2363 (1963).

Regge term of the type mentioned. Major progress has thus been made in setting up the $\pi\pi$ dynamical equations for solution. (C. Edward Jones)

An attempt is being made to find a relativistic generalization of the Regge formalism via the infinite-dimensional irreducible representation of the proper Lorentz group. (Jack Wong)

Investigation into the general theory of Regge poles has been conducted, with particular attention to the Regge behavior of the Bethe-Salpeter amplitude. Recent attention has also been given to the Gribov discussion of essential singularities in the relativistic scattering amplitude at negative-integer values of angular momentum. (John Hutchins)

The possibility of the f^0 particle's lying on the Pomeranchuk trajectory has been investigated. Some currently assumed properties of this trajectory have been used to derive a bound for the values of the trajectory for negative t, for a given value of the energy of the Pomeranchuk particle. This bound is compared with the published analysis of the high-energy p-p differential cross sections and the conclusion is that "either the slope of the Pomeranchuk trajectory has been seriously overestimated from the p-p data, or the Pomeranchuk particle is likely to have an energy less than or approximately equal to the ρ meson energy."[16] (Alberto Pignotti)

A bootstrap calculation of π-K scattering is in progress. The present results indicate that the ρ-meson exchange is the main attractive force acting on the K^* resonance. This would rule out the assignment of $I = 3/2$, $J = 1$ to the 730-MeV resonance, because in this state the ρ force is repulsive. The possibility of the latter resonance's being an S-wave $I = 1/2$ state is under investigation at present. The direct forces acting on this state are attractive and are the same responsible for the K^* resonance. Furthermore, the K^* exchange is also attractive. Finally the exchange of the same 730-MeV resonance is expected to provide the long-range repulsion necessary to "bind" an S-wave resonance, in which no repulsive centrifugal barrier is present. (Alberto Pignotti)

A method developed for the calculation of the nucleon trajectory has been applied to the Pomeranchuk trajectory. With a four-parameter expression for the imaginary part of the angular momentum, and by using a once subtracted dispersion relation, the real part has been calculated. The unknown parameters are determined from the known conditions and experimental information about the trajectory. The resulting nonlinear equations give a trajectory that is in good agreement with the most recent experiments. Also on the basis of the calculated trajectory, attention has been drawn to the discrepancy that, if the newly discovered particle f^0 is interpreted as the Pomeranchuk particle, the tail of the trajectory (as calculated from the high-energy scattering data assuming only the Pomeranchuk particle contributes at

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16. Alberto Pignotti, Does the f^0 Particle Belong to the Pomeranchuk Trajectory? UCRL-10600 Rev. (to be published in Phys. Rev. Letters).

these energies) cannot be correct, or vice versa. This paper, "An Approximation Method for Regge Trajectories and its Implications on the Spin-2 Particle of the Chew-Frautschi Diagram," has appeared as UCRL-10584, Dec. 1962. (Akbar Ahmadzadeh and Ismail Sakmar)

The work on high-energy kaon-nucleon scattering is in progress. The contributions of different Regge poles in each channel to the forward and backward scattering cross sections have been calculated. Special emphasis has been given to the fermions exchanged in the $\bar{K}N \rightarrow \bar{K}N$ channel. By making use of the MacDowell reflection principle and the real analyticity possible characteristics of the fermion, Regge trajectories are derived and the Regge poles of the u channel are investigated by looking for possible connections between them. It has also been shown that the Regge formalism cannot be applied to a certain region of the Mandelstam diagram for unequal-mass particle scattering. This makes it impossible to use real Regge poles at finite but high energies. From knowledge of the crossing matrices for the invariant amplitudes, the crossing relations for the amplitudes of the problem have been worked out. Finally the total cross sections and different combinations of them are given. (Ismail Sakmar)

A method of approximating Regge trajectories in the relativistic case has been developed. The method is applied to the Pomeranchuk trajectory, and certain deductions have been made.[17] In particular it is found that, if the f^0 particle is on the Pomeranchuk trajectory, $\alpha'(0) \approx 0.5\ \mathrm{BeV}^{-2}$ in contrast to $\alpha'(0) \approx 1\ \mathrm{BeV}^{-2}$. The result of the approximation is in reasonable agreement with the high-energy p-p scattering reported by Lindenbaum, et al.[18] (Akbar Ahmadzadeh and Ismail Sakmar)

By use of some explicit examples of a single-attraction Yukawa potential in nonrelativistic scattering, it has been shown that $\alpha(k^2)$ satisfies a dispersion relation with one subtraction. It has also been shown that in this case $B(k^2) = \beta(k^2)e^{-i\pi\alpha}$ is a real analytic function with only a right-hand cut and that it satisfies a dispersion relation without subtraction. It has been further shown that the reduced residue $b(k^2) = \beta(k^2)/(k^2)^{\alpha+1/2}$ satisfies a dispersion relation with subtraction, the number of subtractions depending on the order of the trajectory. By an explicit example it can be shown that for a repulsive potential $\alpha(k^2)$ does not satisfy a dispersion relation; this is blamed on the fact that $\alpha(k^2)$ must have complex branch points. Additionally, the threshold behavior of the fermion trajectories has been investigated; work on this is in progress. An attempt is also under way to find a suitable combination of Yukawa potentials in the nonrelativistic case that would produce

17. Akbar Ahmadzadeh and Ismail Sakmar, An Approximation Method for Regge Trajectories and its Implications on the Spin-2 Particle of the Chew-Frautschi Diagram, UCRL-10584, December 5, 1962.

18. K. J. Foley, S. J. Lindenbaum, W. A. Love, S. Ozaki, T. T. Russell, and L. C. L. Yuan, 7-20 BeV/c $\pi + p$ and $p + p$ Elastic Scattering and Regge Pole Predictions, Brookhaven National Laboratory Preprint, 1963.

relativistic-looking trajectories; also, studies of the convergence of two series expansions for the partial wave amplitude, one by Chew[19] and another by Khuri,[20] are being made. (Akbar Ahmadzadeh)

The theory of an extrapolation procedure proposed by T. Regge has been developed. The method yields an arbitrary phase shift if (a) any infinite subset of the phase shifts is given at a particular energy, and (b) the positions of Regge poles are known. The general mathematical requirements on the phase shifts for applicability of the method have been investigated; these involve the properties of a class of functions, the Pollachek polynomials. Consequently, appropriate limiting forms of their behavior have been found. The extrapolation procedure has also been explored numerically and a computer program was written to reconstruct the value of an analytic function at an arbitrary point on the real axis, given its values on a set of integrally spaced points on the real axis. When applied to a particularly well-conditioned function it was found to yield excellent results (0.001 % accuracy). Attempts to apply it to empirically determined proton-proton phase shifts, supplemented by the theoretical one-pion-exchange contribution, were frustrated by the large number of input points required to yield reliable results. Calculations are still in progress to determine its applicability to cases involving Regge poles. (Graham Campbell, Joseph V. Lepore, and Robert J. Riddell, Jr.)

A comprehensive study[21] of final-state interactions in scattering processes has been completed. Extensive use of the Jost function formalism has allowed unification of several techniques developed for final-state effects. A method involving solutions to a set of singular integral equations has been applied to the photodetachment of negative ions. The possibility of detecting pair interactions in final states with incompletely determined kinematics has been investigated. (John Gillespie)

With Dr. A. C. Finn of Stanford University, work has been completed on a special case of the problem of three simultaneous two-body final-state interactions. The particular limit in which this problem is discussed is that in which two of the interactions are of long range and slowly varying while the third is of short range. The presence of the long-range interactions then merely alters the energy at which the short-range interaction takes place. This observation allows (a) a correction to the s-wave pion-pion scattering length as deduced from the He^3 experiment, and (b) predictions for the shift in the energy of the ρ and N^* resonances when they are produced in complex nuclei. (V. L. Teplitz)

Work on Weinberg's quasiparticle theory[22] applied to short range potentials has just been completed. Bound states and scattering lengths were calculated almost exactly from a lowest-order quasi-Born approximation. The way is now clear to prove that perturbation theory in strong interactions works if one takes into account the elementary particles and resonances in a "quasiparticle" fashion. (Michael Scadron)

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20. W. Khuri, Institute for Advanced Study Preprint, Princeton Univ. (1962).

21. John Gillespie, The Effects of Final State Interactions in Scattering Processes, UCRL-10762, March 9, 1963 (unpublished).

22. Steven Weinberg, private communication.

The mass spectra of the vector mesons in the limit of exact octet symmetry has been calculated, by requiring the vector mesons to generate themselves self-consistently as resonances in pseudoscalar meson—pseudoscalar meson scattering. In the initial stages of this calculation, possible effects from coupled inelastic channels are neglected. In this approximation a decuplet with $J^P = 1^-$, as well as the octet, will resonate, and possibly also a singlet with $J^P = 0^+$. It is entirely possible this decuplet may still exist, even in the presence of the interactions violating octet symmetry, as a group of resonances in the as yet unexplored energy region above 1 BeV. The effect of inelastic channels on this decuplet is being studied. (Donald E. Neville)

Work was begun on a study of unitary symmetry and its applications to some simple problems. Branching ratios of π_a mesons ($T = 1$, $J = 0$, $P = +$, $G = -$) were calculated. The influence of SU_3 on threshold effects is being investigated. (Jon A. Wright)

PHYSICS OF THE NUCLEUS

The tabulation of the properties of a rotating charged drop, representing an idealized nucleus with high angular momentum, has been completed. The tabulation covers all conditions that can be found in the bombardment of any target in the periodic table by an arbitrary heavy ion. For each compond system an absolute upper limit on the amount of angular momentum that can be supported by the nucleus without disruption has been established. A quantitative definition of "breakup reactions," observed experimentally in certain heavy-ion interactions, appears possible in terms of this upper limit. For angular momenta below this limit, two distinct regions of conditions have been found, characterized by oblate (pseudospheroidal) and triaxial (pseudoellipsoidal) shapes of the equilibrium of the drop. The relations of these results to the analogous situation in the astronomical discussions of rotating gravitating masses has been established in a quantitative way by tracing all calculations as functions of the relative magnitude of the electrostatic energy into the region of negative values, where the electrostatic energy changes into a gravitational energy. The work was done in collaboration with S. Cohen of the Argonne National Laboratory and with Frank Plasil of the Chemistry Division. A paper describing the results was presented by Frank Plasil at the Third Conference on Reactions Between Complex Nuclei held at Asilomar, California, April 1963. (W. J. Swiatecki)

The work on a nuclear mass formula that takes shell effects and nuclear deformations into account has continued. Comparisons with the one thousand experimental masses and a few dozen experimental deformations have been made, and approximate values of the parameters in the mass formula have been established. (W. J. Swiatecki)

Results have been reported concerning distributions of fission-fragment kinetic energy, deduced from a model in which a fissioning nucleus is represented by an idealized charged drop whose shape is constrained to the family of shapes generated by two overlapping or separated

spheroids.[23] This work treated a restricted case in which the two spheroids are completely symmetrical; the model in its more general asymmetric noncollinear form is now being studied. Computer codes have been written that calculate the interaction energy of two separated noncollinear spheroids and the saddle-point stiffness constants. Various other distributions associated with the fission process, such as the distributions of excitation energy and rotational energy of fission fragments, are being calculated on the basis of the model. (James Rayford Nix)

THEORY OF MANY-BODY PROBLEMS

Work has continued on the many-body theoretical calculation of the low-temperature properties of liquid He^3. A separable potential, which was previously obtained, was employed in preliminary calculations analogous to the work of Puff and of Falk and Wilets on nuclear matter. These computations indicated that a more refined calculation would be both necessary and of value, and such a calculation is presently in progress. (Donald Beck and Andrew M. Sessler)

An investigation, with Gordon Baym of the University of California Physics Department, of perturbation theory in quantum statistical mechanics was initiated and completed during the period. The work is described in a paper submitted for publication in Phys. Rev.[24] (Andrew M. Sessler)

An investigation is being made of the effect of interparticle forces on the condensation temperature T_c of a system of bosons. By use of the general quasiparticle formalism of Bloch, Balian, and de Dominicis, it was demonstrated that previous studies of this problem, by other workers, have involved an expansion which is formally correct but demonstrably nonconvergent. A proper perturbation theory in the interparticle forces has been derived and used to obtain two coupled integral equations for T_c in the approximation of weak interparticle forces. These equations are now being used in an attempt to gain insight into the condensation of liquid He^4, in which the interparticle forces are not weak, by first obtaining an effective weak inter-quasi-particle potential. (Victor Wong and Andrew M. Sessler)

A system with a large percentage of He^3 but a small percentage of He^4 is being studied. It is our intention to calculate the effective mass of He^4 in the solution, and to investigate the effect of statistics in the intermediate state. Numerical results remain to be obtained. (Chi C. Sung)

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23. James Rayford Nix, Estimates of Fission-Fragment Kinetic-Energy Distributions on the Basis of the Liquid-Drop Model, UCRL-10695, April 1963; to be published in Proceedings of the Third Conference on Reactions Between Complex Nuclei, Asilomar, California, April 1963 (University of California Press).

24. G. Baym and A. M. Sessler, Perturbation-Theory Rules for Computing the Self-Energy Operator in Quantum Statistical Mechanics, UCRL-10562, December 17, 1962.

A variational H theorem is used to calculate thermodynamical properties of different systems. In Heisenberg's model of ferromagnetism the result is the same as that derived from the Green's function method. (Chi C. Sung)

The perturbation technique developed by Kaufman and Watson[25] has been applied to the problem of electrostriction in a nonideal gas at equilibrium. Expressions have been obtained for the density and pressure as functions of position. (Louis T. Klauder, Jr.)

As previously reported (Physics Semiannual Report UCRL-10572, Nov. 1962), a functional integral formulation for the thermodynamic functions of a nondegenerate quantum plasma has been completed. This formalism yields expressions for the thermodynamic functions which are exactly analogous to the classical irreducible virial expansions, and which are particularly convenient for expansions about the classical limits. In order to obtain quantum corrections to the classical second virial coefficient of an electron gas interacting via an effective screened potential (a nonlocal two-body potential derived from the random-phase approximation), the functional integral formalism has been utilized. Calculations are now under way to find these quantum corrections, and it is expected that the results will be obtained within a few months. (Sidney Putnam)

The correlation energy calculations of beryllium have been completed and the work is described in Hugh P. Kelly, "Correlation Effects in Atoms (Thesis) UCRL-10471, Oct. 1962. Application of many-body perturbation theory to open shell atoms is being investigated. An unrestricted Hartree-Fock calculation has been made for oxygen; some preliminary results have been obtained for the correlations among 2p electrons in this atom. (Hugh Kelly)

ATOMIC PHYSICS

The scattering of electrons by neutral atoms is being studied by a generalized Hartree-Fock technique. Work on electron-neon scattering has been completed and is now being extended to the case of sodium. (Marvin H. Mittleman and Kenneth M. Watson)

The calculation of electron-hydrogen scattering phase shifts for the energy range 0 to 9.6 eV, using the generalized optical potential method previously developed, has been completed. In particular, a value of 6.52 (Bohr radius units) for the singlet s-wave scattering length is obtained. The results have been reported.[26] (Robert T. Pu)

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25. Allan N. Kaufman and Kenneth M. Watson, Phys. Fluids 4, 655, 931 (1961).

26. Robert T. Pu, A Generalized Optical Potential Method and its Application to the Scattering of Electrons by Atomic Hydrogen, (Ph. D. Thesis, University of California, Berkeley).

Two problems are now being considered: first, the calculation of the singlet s-wave scattering using a modified trial wave function form; and second, the determination of whether the "resonance" phenomenon exhibited in all close-coupled-states types of calculations is of spurious nature and arises only mathematically. (Robert T. Pu)

The Kohn-Hulthén variational principle is being applied to calculate numerically the phase shifts in the elastic scattering of an electron from a neutral hydrogen atom. To simplify the integrations, the usual asymptotic form of the wave function has been altered by replacing the spherical Neuman function by a combination of spherical Bessel functions. This calculation is now in progress on the IBM 7090 computer. Calculations will be made for angular momenta equal to one and higher units. (Robert L. Armstead)

The effect of correlations among atomic electrons was studied by applying the random-phase approximation to the calculation of atomic excitation energies, oscillator strengths, and photo-ionization cross sections.[27] The random-phase approximation was found to be inadequate in certain instances, and methods to improve it are now being investigated. In particular, the computation of a photo-ionization cross section in a region where autoionization lines are present requires an extension of the random-phase approximation. The object of the present study is to make such an extension and perform numerical calculations on calcium. (Philip L. Altick)

Exact calculations on a mathematically tractable model analogous to proton-hydrogen-type scattering have been completed. The transition probabilities attained for processes involved in both direct and capture collisions will be used to evaluate results derived from standard approximation methods[28] which are now under way. (James Quong)

A method for determining the phase of a scattering amplitude by direct measurement has been proposed. Its experimental application requires the use of coincidence counting techniques. We have developed the theory of the method for the case of the intensity correlations of x-ray scattering. The same idea may also be extended to the scattering of other particles. (K. M. Watson)

PLASMA PHYSICS

Preliminary studies have been made to improve the derivation of the kinetic equations of a plasma. An attempt is made to describe a classical system of many particles in the Fock space, as it has been shown that the method of second quantization is independent of Planck's constant and is therefore equally applicable to classical systems. It is hoped that a convenient method can be developed to obtain the collision terms of the kinetic equations and to determine the properties of the distribution and correlation functions for stable and unstable plasmas. (Rudolph C. Hwa)

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27. Philip L. Altick, The Randon-Phase Approximation Applied to Atomic Structure, UCRL-10510, October 15, 1962 (unpublished).

28. Marvin Mittleman, Phys. Rev. 122, 499 (1961).

Investigation has been continued of the interaction of radiation with a plasma by means of the Green's function method. Calculation of the stopping power of a photon is still under study; a direct calculation of the bremsstrahlung in a plasma has been submitted for publication in Phys. Fluids.[29] Presently under study are nonlinear effects in the interaction of radiation with a plasma, the research being motivated by the intense beams now becoming available from lasers. (John Stack and Andrew M. Sessler)

A further study has been made of the usefulness of correlation techniques in analyzing laser light scattered by a plasma. The hope is that such a technique may reduce problems with stray scattered light. Questions regarding photon correlations in the light from a single laser have been raised recently in the literature. To avoid these uncertainties it seems clear that two lasers of different polarization or wavelength would be needed as sources. (Theodore G. Northrop)

A review of adiabatic charged-particle motion, with particular emphasis on geophysical applications, has been submitted to Rev. Geophys. (Theodore G. Northrop)

The stability of a mirror machine with conducting end plates is being studied by means of various energy principles. The conducting end plates tie down the magnetic lines of force and thus inhibit the flute instability. The energy principles are of the form $\delta W = \langle u, Lu \rangle$, where u is a trial displacement in the plasma, and L is a linear, self-adjoint operator. The procedure is to minimize δW with respect to u, subject to a normalization condition. This leads to an eigenvalue equation of the Sturm-Liouville form. We then have $\delta W_{minimum} = \lambda_1$, where λ_1 is the lowest eigenvalue. The condition that the configuration is stable is $\lambda_1 > 0$. The theory of variational methods furnishes a lower and an upper bound for λ_1. The condition that the upper bound of λ_1 be greater than zero is a necessary condition for stability, whereas the condition that the lower bound be greater than zero is sufficient for stability. By employment of the above technique, a necessary condition for stability in a collision dominated plasma was found by using the Matterhorn energy principle.[30] This energy principle is useful for a scalar pressure. In the anisotropic case, a necessary condition for stability was found for the Chew-Goldberger-Low energy principle,[31] and a sufficient condition for stability was derived by use of the energy principle of William Newcomb.[32] Present work consists of evaluating the necessary condition of the Matterhorn energy principle for a particular mirror-machine configuration suggested by Harold Grad.[33] A plot of the optimum $\beta = 2p/B^2$ vs mirror ratio and aspect ratio is being constructed by numerical techniques. (Shalom Fisher)

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29. John Stack and A. M. Sessler, Bremsstrahlung in a Dense Plasma, UCRL-10628, January 15, 1963 (submitted to Phys. Fluids).

30. I. B. Bernstein, E. A. Frieman, M. D. Kruskal, and B. M. Kulsrud, Proc. Roy Soc. (London) A244, 17 (1958).

31. Ibid.

32. William Newcomb (Lawrence Radiation Laboratory, Livermore), private communication.

33. Harold Grad, Second United Nations International Conference on the Peaceful Uses of Atomic Energy, 31, 187 (1958).

A. N. Kaufman[34] and W. B. Thompson[35] have discussed first-order (in gyration radius) corrections to the usual diagonal pressure tensor for a fully ionized plasma in a large magnetic field. These corrections are necessary to introduce finite Larmor radius effects into hydromagnetic calculations. The results given by these authors agree except for the component P_{12}, where $\hat{e}_1$ is the unit vector parallel to the magnetic field and $\hat{e}_2$ and $\hat{e}_3$ are the perpendicular vectors. Neither author gives P_{12} correctly. Thompson obtains his result from a B^{-1} expansion. He finds a contribution to P_{12} proportional to the hydrodynamic derivative of $\hat{e}_1$, $d\hat{e}_1/dt$, which turns out to be equal to $(\hat{e}_1 \cdot \nabla V)_3$ because of Maxwell's equations and the zero-order condition $\vec{E} + \vec{V} \times \vec{B} = 0$. Thompson's result is correct except for the sign of this contribution. Kaufman is interested in clarifying the mechanism responsible for the off-diagonal components of the pressure tensor. He assumes that the only contributions to these components are from velocity gradients, and then calculates the contributions to each component by considering the particle orbits occurring when only one of the components of $\vec{\nabla}\vec{V}$ is nonvanishing. The magnetic field is taken to be constant in space and time. However, as mentioned above, a nonvanishing $\hat{e}_1 \cdot \nabla V_3$ must be accompanied by a nonconstant magnetic field, contradicting Kaufman's assumption. The effect of the necessary variation in magnetic field is easily included in Kaufman's calculation, and the resulting P_{12} then agrees with that obtained by Thompson's method (but given incorrectly by Thompson). (Alan Macmahon)

THEORY OF ACCELERATOR AND ACCESSORY INSTRUMENTS

Work continued on problems related to the design of a large proton synchrotron. In particular, parameter studies for machines in the range 100 to 300 BeV were reviewed, the relative merits of various types of injectors were studied, and some progress was made on the question of orbit resonances in the presence of space charge. (Lloyd Smith)

In connection with the startup of the Bevatron, an analysis was made of the effect of beam loading on the rf system. Formulas were developed for phase and amplitude changes in various parts of the system and for a small-amplitude instability that arises for coherent phase oscillations of the beam. (Lloyd Smith)

A study was made of the extraction of particles from a multi-hundred-BeV alternate-gradient synchrotron. A method (similar in principle to one proposed by Hereward) employing a perturbing magnet, which is slowly moved near the circulating beam was studied analytically and computationally. The proposed scheme employs the nonlinear nature of the betatron oscillations to slowly slip particles across the separatrix and hence out of the accelerator. It was demonstrated that slow (or rapid, if desired) extraction of almost all of the internal beam, with very good beam quality, is possible. This work will be the basis of further study with the goal of relaxing the requisite tolerances,

34. Allan N. Kaufman, Phys. Fluids 3, 610 (1960).

35. W. B. Thompson, Reports on Progress in Physics 24, 363 (1961).

optimizing the choice of parameters, and eventually fixing on a detailed engineering design. (Andrew M. Sessler)

Work has continued on the use of the Fermi (relativistic version) statistical model to estimate the secondary-particle beams of a future very-high-energy accelerator. Numerical studies are in progress to compare the results of model predictions with experiment. Resonant final-state interactions are treated as final-state particles that decay independently of the central reaction. It has been demonstrated that the pion multiplicities from $\bar{p}$ - p annihilation at rest can be fitted by this procedure with unmodified interaction volumes. (Graham Campbell)

During a three month period last fall at the Rutherford High Energy Laboratory in Great Britain, we developed computer programs to aid in the design of a spiral-ridge cyclotron similar to that at Berkeley. These were used in the planning of a deflector system, pole face windings, etc. Upon learning that encouraging experiments had been carried out on the Birmingham radial-sector cyclotron with peeler-regenerator extraction, we applied a generalization of LeCouteur's theory for this mechanism to spiral-ridge cyclotrons. Numerical calculations reveal a strong dependence of radial growth rate on the azimuthal positioning of the perturbing elements. (Alper Garren)

Recently the flexibility of the 88-inch cyclotron has been considerably increased. This cyclotron now has yielded beams of α particles, He_3^+, and protons at various energies. A technique has also been developed for determining and improving the beam phase behavior by employing measurements of intensity vs radius on a probe; additionally, a method was devised for determining the radial amplitudes of the beam from two-probe shadow measurements. These contributions are to be reported at the 1963 International Conference on Sector-Focused Cyclotrons and Meson Factories at CERN.[36] (Alper Garren and Lloyd Smith)

A comprehensive study of the aberrations of quadrupole magnet beam systems has been completed. Sixty-four coefficients characterize the third-order aberrations; there are no geometric aberrations of second order due to the two-plane reflection symmetry properties of quadrupole magnets. An IBM 7090 computer program, which, using the techniques of linear programming, calculates the aberrations of arrays of quadrupole magnets and optimizes optical properties of beam systems was described in the preceding progress report. The output of this code has been complemented by a comprehensive set of cathode ray tube plots. Plots of the beam envelope and phase-space plots readily yield the first-order properties of a beam. Quantitative and qualitative detail on the nature of the aberrations is contained in the plots of the projections on the three Cartesian coordinate planes of representative groups of trajectories at the exit of the beam system. Expressions for the maximum and root-mean-square displacements due to aberrations have been derived. Several typical arrays of quadrupole magnets have been studied with the code; in these examples the inherent aberrations of the

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36. Alper Garren and Lloyd Smith, Diagnosis and Correction of Beam Behavior in an Isochronous Cyclotron, UCRL-10756, April 2, 1963, for the Proceedings of the Meeting of the 1963 International Conference on Sector-Focused Cyclotrons and Meson Factories, CERN.

quadrupole magnets limited the performance of the systems. Appreciable reduction of the aberrations was observed upon increasing the separation of the quadrupole magnets; the gradients were adjusted to leave the focal and magnification properties unchanged. (Philip F. Meads, Jr.)

The theory of beta-ray spectrometers was investigated; it was shown how to employ azimuthally varying fields to design a spectrometer of increased aperture. This work will be the basis of a detailed design study which is now under way. The basic idea is described in a letter submitted for publication.[37] (Andrew M. Sessler)

MISCELLANEOUS STUDIES

The effort to understand the transitions made by a μ^- meson captured in a high n state in solid lithium is nearing completion. By use of certain reasonable approximations, rates for various competing transitions (radiation and Auger involving core and band electrons) have been computed, and transition paths have been followed from various initial capture states. By assuming the validity of these results, it was found that qualitative statements concerning the transition paths of both π^- and μ^- mesons captured in light elements ($Z \leq 6$) could be made. It is hoped a detailed report of this work will be ready soon. (Coates R. Johnson)

In progress are some cosmological calculations relating the minimum radius in an oscillating-universe model to the flux of muon neutrinos in the universe, for which experimental data will soon be available. (Alexander Maksymowicz)

Amplitudes for the scattering of arbitrarily polarized Dirac particles were obtained by using the two-component spinor formalism of Stapp.[38] Trace calculations were eliminated in favor of direct matrix multiplication while the amount of computational work was kept about the same. For a given process a single calculation gave the amplitudes for the scattering of particles in all possible combinations of helicity states. From these, the amplitudes for scattering of particles in arbitrary polarization states could easily be calculated, as shown by Stehle.[39] The results were used to compute the cross section for scattering of longitudinally polarized muons by arbitrarily polarized electrons, which will be investigated experimentally. (Alexander Maksymowicz)

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37. Andrew M. Sessler, Beta-Ray Spectrometer with Reduced Spherical Aberration (UCRL-10668, February 4, 1963), submitted to Nucl. Instr. Methods.

38. Henry P. Stapp, Lectures on the S-Matrix Theory, UCRL-9875, September 25, 1961 (unpublished).

39. P. Stehle, Phys. Rev. 110, 1458 (1958).

PHYSICS RESEARCH

Edward J. Lofgren in charge

DETERMINATION OF THE Σ^0-Λ^0 RELATIVE PARITY

Allan Clyde, Victor Cook, Bruce Cork, Richard Crolius, Denis Keefe, Leroy T. Kerth, William M. Layson, and William A. Wenzel

The major effort of the group has recently been directed toward the planning, design, setup, and operation of a spark chamber experiment with the object of determining the Σ^0-Λ^0 relative parity. The existing assignment of even parity is based on experiments which rely either on a phase-shift analysis or knowledge of electromagnetic form factors for their success. The present experiment avoids such dependence, relying basically on generally accepted conservation principles. The reactions of interest are

$$\pi^- + p \rightarrow \Sigma^0 + K^0 \hookrightarrow \pi^+ + \pi^-$$
$$\hookrightarrow \Lambda^0 + \begin{cases}\gamma \\ e^+e^-\end{cases}$$
$$\hookrightarrow p + \pi^- \quad .$$

In the first part of the experiment the normal Σ^0 decay ($\Sigma^0 \rightarrow \Lambda + \gamma$) is being observed for 1.325-BeV/c incident pions. The asymmetrical decay of the Λ^0 is used to measure the Σ^0 polarization. If it is not appreciable at 1.325 BeV/c, we will use pions of other momenta in the hope of finding significant polarization. In the second part of the experiment, the Dalitz decay of polarized Σ^0's ($\Sigma^0 \rightarrow \Lambda^0 + e^+ + e^-$) will be observed. The correlation between the Σ^0 polarization, the Λ^0 decay, and the plane of electron pair gives the Σ^0-Λ^0 relative parity.

In the experiment the tracks of the six charged particles resulting from the desired reaction in a liquid hydrogen target are observed in two semi-cylindrical spark chambers. The triggering system includes an array of 48 scintillation counters designed to select sixfold events. A novel method of stereo photography is employed to obtain precise depth information about the tracks in these chambers. The scanning and fitting of events is proceeding simultaneously with the operation.

ELASTIC AND INELASTIC p-p SCATTERING, 2 To 6 BeV

Allan Clyde, Bruce Cork, Denis Keefe, Leroy T. Kerth, William M. Layson, and William A. Wenzel

Preparations are being made to use the external proton beam to improve the accuracy and extent of the p-p elastic scattering measurements previously made by this group. The finer details of the Regge pole theory can be checked because higher momentum transfers and lower rates than those heretofore obtained can be studied. The momentum spectrum of the protons from p-p collisions will also give information as nucleon-isobar production.

π-π INTERACTION

Denis Keefe, Leroy T. Kerth, Carl M. Noble, J. J. Thresher,* William A. Wenzel, and Theodore F. Zipf

For approximately one month in June, 1962, an experiment was run in the Bevatron to measure the dipion mass spectrum ($\pi^- + p \rightarrow \pi^- + \pi^+ + n$) from threshold to 1.5 BeV with a resolution of approximately 0.03 BeV. The Sagane magnet was employed as a momentum analyzer for the final-state pions. At that time, about one million pictures were taken, of which only 50,000 or so will be measured. As was mentioned in the previous semi-annual report, an extensive computer system of programs is needed for the analysis. Three members of the programming division and one graduate student in physics have completed the system, which is now in the debug stage. The system includes fiducial calculation, optical distortion corrections, spatial reconstruction, orbit integration through the 3-D magnetic field, and kinematical fitting. The scanning and measuring is done on SCAMP and so far about 3,000 events have been measured out of 60,000 scanned. It is hoped that the system will be debugged soon and that some preliminary results will be available in June, 1963.

K^--PROTON INTERACTIONS

E. F. Beall, Victor Cook, William R. Holley, Denis Keefe, Leroy T. Kerth, J. J. Thresher,* Ching Lin Wang, and William A. Wenzel

The analysis of the data collected on K^--p interactions between 700 and 1400 MeV/c continues. The two-prong events found in 360,000 spark chamber pictures were scanned and measured by using the SCAMP system while an IBM-7090 program was being written and debugged for the analysis of the elastic scattering events. The separation of elastic from other two-prong events has begun, and preliminary results indicate that about one-third of those measured will fit elastic kinematics. An analysis of corrections to the data is now under way as is a program of rescanning to determine efficiencies and biases.

A second computer program has been written for fitting two-prong events to reactions of the types

$$K^- + p \rightarrow \overline{K^0} + X$$
$$\rightarrow \Lambda^0 + X,$$

where X is the missing mass to be determined.

Thus far the analysis indicates that the separation of the reactions

$$K^- + p \rightarrow \overline{K^0} + n$$
$$\rightarrow \overline{K^0} + n + \pi^0$$
$$\rightarrow \Lambda + \pi^0$$

*Visitor from Rutherford High Energy Laboratory, National Institute for Research in Nuclear Science, Chilton, Didcot, England.

is possible only for a very limited number of events, whereas a large portion fit two or more hypotheses. A more elaborate investigation might reduce this difficulty.

The polarization of the elastically scattered protons can in many cases be determined from the secondary scattering in the carbon plates of the spark chamber. The related scanning and measurement is under way and a program for the analysis is now being written.

SPARK CHAMBER DEVELOPMENT

Bruce Cork and Denis Keefe

Tests of spark chambers operated with various gas mixtures, contaminants, and plate coatings have been made, and the testing program will continue.

ELECTRON LINEAR ACCELERATOR

Douglas W. Pounds

During the period October through May, beam time for experimenters amounted to 650 hours or about 68% of the available time. The remainder of the time was devoted to experimenter setups, machine modifications and maintenance, and continuing facility modifications.

The principal groups utilizing the machine during this period were Physics (Thornton-Ruby), Health Physics, Biophysics, NASA (via Bio-Organic Chemistry), Bevatron, UC Soils and Plant Nutrition, and Plant Pathology.

Major facility modifications have been addition of 400 square feet of experimenter and equipment area, additional shielding to compensate for the higher intensities and energies, and installation of an electron paramagnetic resonance spectrometer with associated equipment belonging to the Biophysics group. (This device has not reached operational status at this time. However, this is expected shortly, possibly by early May.)

The normal operating maximum of the accelerator has been raised to 6.5 MeV although the 10 MeV level is still awaiting the acquisition of 5-mW rf windows and necessary accelerator matching.

Normal operating conditions at present are as follows:

Maximum run conditions greater than 1/2 hour
120 pulses/sec,
100 mA/pulse,
6 μsec pulse width,
6.5 MeV.

Maximum run conditions less than 1/2 hour

240 pulses/sec
125 mA/pulse
6 μsec pulse width
6.5 MeV

Pulse rate is variable in preset steps from single pulse to 240 pulses/sec.
Beam intensity is variable from 0 to 125 mA/pulse.
Beam energy is variable from 100 to 200 keV, and from 1 to 6.5 MeV.
Pulse width is variable from 1 to 6 μsec.
Beam diameter at exit end is about 1 in^2.

The outlook for the coming six-month period is for a small increase in experimenter beam time due to the inclusion of the Biophysics EPR program, the expected conclusion of the 10-MeV program, and an initial study into the feasibility of adding a section to the accelerating column. The additional section would enable the machine to utilize more of the available rf energy, with a resulting increase in energy output. Present efficiency is about 50% with a 4-ft accelerating section.

PHYSICS RESEARCH

Burton J. Moyer and A. Carl Helmholz in charge

RADIATIVE CAPTURE OF NEGATIVE PIONS IN FLIGHT

William C. Bowman, Jim B. Carroll, Robert W. Kenney, and John A. Poirier

An experiment has been done at the 184-inch cyclotron to study the reactions

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

and

$$\pi^- + p \rightarrow \gamma + n. \qquad (2)$$

The incident π^- kinetic energy was alternated between 50 MeV and 0 MeV. The two reactions (at both energies) were separated by measuring the energy of the gamma rays with a total absorption counter [see Rev. Sci. Instr. 33, 741 (1962)]. The gamma counter was placed at an angle that corresponded to 90 deg c.m. for reaction (2).

Analysis of the data taken in this experiment is continuing. The energy spectrum of photons produced in reactions (1) and (2) as obtained with a pulse-height analyzer has been transferred to magnetic tape for study with the 7090 computer. Photographs of oscilloscope traces containing information about possible background contaminations of the photon spectrum are also being studied.

With the same experimental arrangement as above, the target was filled with liquid deuterium to study the reactions

$$\pi^- + d \rightarrow n + n \qquad (3)$$

$$\pi^- + d \rightarrow n + n + \gamma \qquad (4)$$

and

$$\pi^- + d \rightarrow n + n + \pi^0. \qquad (5)$$

Approximately 60,000 pictures of oscilloscope traces of our counters' pulses have been analyzed for these types of interactions. The data are equally divided between stopping and 50-MeV incident pions.

The large total-absorption scintillation counter was used to observe the final states of reactions (3), (4), and (5). The counter was sensitive to both neutrons and gamma radiation although only the neutrons of reaction (3) were fast enough to be within the resolving time of the electronics. To distinguish between reactions (3), (4), and (5) it was necessary to separate the gamma energy spectrum from the neutron energy spectrum as well as from background events. An attempt is being made to separate neutrons from gammas by taking advantage of differences in their velocities. A set of Gaussians was fitted to the time-of-flight distribution in order to quantitatively determine the spectra.

The output of the total-absorption scintillation counter was also stored in a pulse-height analyzer. These data, coupled with the film data for the cases of stopping negative pions in hydrogen and deuterium, give the ratio of radiative capture in deuterium to that in hydrogen. A preliminary number is

$$T = \frac{\omega(\pi^- + d \rightarrow n + n + \gamma)}{\omega(\pi^- + p \rightarrow n + \gamma)} = 0.80,$$

with an error of about 10%. As soon as several corrections have been more fully analyzed, the error can be reduced somewhat.

The cross sections for $T_\pi = 50$ MeV have yet to be calculated. Preliminary analysis of the data indicates that an accuracy of about ± 20% can be expected.

PROTON POLARIZATION IN ELASTIC πp SCATTERING

Richard Eandi, T. Devlin, Robert Kenney,
Paul McManigal, and Burton J. Moyer

A spark chamber experiment was performed in the Fall of 1961 to study the polarization of recoil protons at pion energies between 500 and 100 MeV. The film taken has been scanned and all film analysis completed.

With present available data on the analyzing power of carbon, results for the recoil proton polarization as a function of pion scattering angle have been calculated for 523, 572, and 689 MeV incident pion energies. Using these results together with available pion-proton total and differential cross sections measured at nearby energies and restrictive assumptions related to the second resonance, two plausible nonunique sets of phase shifts were obtained for $\pi^- p$ scattering at the second resonance. One set is characterized by a $J = 3/2$, $T = 1/2$, D-wave resonance; the other set is characterized by a $J = 3/2$, $T = 1/2$, P-wave resonance at 600 MeV incident pion energy. More experimental information, such as charge-exchange angular distributions, or recoil proton polarization data with far smaller statistical uncertainty, is needed to ultimately obtain a unique set of angular momentum amplitudes (phase shifts) which will completely determine pion-nucleon scattering at these energies. The data together with the phase-shift analysis results have been reported.[1]

To completely analyze the film data for pion energies above 700, data for the analyzing power of carbon at higher energies are needed. To obtain these data, a calibration experiment using a proton beam of known polarization and involving the same spark chambers was performed at the cyclotron in the Fall of 1962. A large portion of the film has been scanned; data analysis to obtain the carbon analyzing power as a function of proton scattering angle and energy is now being performed. Upon the completion of

1. Richard D. Eandi, Polarization of Recoil Protons in Pion-Proton Elastic Scattering at 523, 572, and 689 MeV (thesis), UCRL-10629, March 1963.

this analysis, we will obtain the proton polarization angular distributions at 864 and 980 MeV incident pion energies.

A digitized-protractor scanning system has been developed to facilitate scanning and analysis, and has been used to scan the calibration film.

POLARIZATION AND DIFFERENTIAL CROSS SECTIONS IN PROTON-PROTON AND PROTON-NUCLEUS SCATTERINGS AT 730 MeV

Paul G. McManigal

The polarization and differential cross sections in scatterings from eight different elements including hydrogen, helium, and carbon have been measured at the 184-inch cyclotron. Double scatterings, both external to the cyclotron, were used to obtain the polarization results. In order to ensure elasticity of scatterings, the protons were momentum-analyzed after the second scattering by a magnetic spectrometer which deflected them through 102 deg.

Results from this work show a large proton-proton polarization which reaches a maximum of more than 60%. Polarization from the heavier elements remains lower. The experimental results have been used to determine potentials in an optical model. In addition to the above work, which has been completed, spark chambers with carbon plates were calibrated with respect to their analyzing power by placing them in a beam of known polarization. Film scanning and data analysis are now being completed in this phase of the work.

NEUTRON ENERGY SPECTRA FROM NUCLEAR CAPTURE OF μ^--MESONS IN Al, Ca, Fe, Ag, I, Au, AND Pb

Jagdish S. Baijal, Selig N. Kaplan, Donald E. Hagge, and Robert V. Pyle

Nuclear temperatures were deduced from the measured spectra according to the Weisskopf evaporation theory, and results were compared with other experimental measurements of nuclear temperature at similar excitations produced by other processes. A calculation of the direct neutron emission spectrum was made obtaining the nuclear excitation from a degenerate Fermi gas model and direct neutron emission probability from an optical model. The results will be reported shortly in the thesis of Donald Hagge, UCRL-10516.

PION PRODUCTION BY PIONS INCIDENT ON PROTONS

Dale Dickinson, Richard Kurz, Victor Perez-Mendez, Robert Profet, Barry Barish, Don Lind, and Julius Solomon

During this period two experimental runs were done at the 184-inch cyclotron on inelastic π-p scattering.

The first experiment was done in the meson cave using π^- of energies 310 and 370 MeV on the reactions

$$\pi^- + p \rightarrow \pi^0 + n,$$

$$\pi^- + p \rightarrow \pi^0 + \pi^0 + n.$$

The differential cross sections for the neutrons in both reactions were measured by time of flight. The elastic charge-exchange differential measurement showed that previous work had overestimated the yield of elastic neutrons in the forward direction.

A preliminary analysis of the inelastic distribution at 310 MeV shows that the enhancement of high $\omega_{\pi\pi}$ values observed previously at higher energies still persists; the enhancement at $\omega_{\pi\pi}$ = 310 MeV which was expected on the basis of the ABC effect does not appear to be there.

The second experiment was a preliminary run in the proton cave of the cyclotron to study the π^+-induced reactions

$$\pi^+ + p \rightarrow \pi^+ + \pi^+ + N \qquad (1)$$

$$\pi^+ + p \rightarrow \pi^+ + \pi^0 + P, \qquad (2)$$

using spark chambers triggered by inelastic neutrons for (1) and photons for (2).

$\pi^{\pm}p$ PHASE-SHIFT ANALYSIS IN THE HIGHER RESONANCE REGION

Robert J. Cence

Even though the results of polarization are known, the precision of such results is rather low, and ambiguities remain in the phase shifts. We will certainly require the further constraints of the charge-exchange differential cross sections at various energies. Also important will be the extensive elastic scattering data now being accumulated in the energy region between the 3/2, 3/2 resonance and the higher resonances, so that continuity may be established in the energy dependence of phase shifts.

PHYSICS RESEARCH

William A. Nierenberg in charge

ATOMIC BEAM GROUP

The Atomic Beam Group continues to devote most of its effort toward the systematic measurement of various atomic and nuclear properties of radioactive isotopes. Some of the properties measured are nuclear spins, nuclear magnetic dipole and electric quadrupole moments, atomic hyperfine structures and hyperfine-structure anomalies, and electronic g factors. Many of these properties serve one or both of two useful functions in nuclear physics. First, they form test information for theories of the nuclear ground state. Second, nuclear spins act as a base for constructing decoy schemes in beta- and gamma-ray spectroscopy.

Published work appeared during the period of this report as follows.

(a) F. R. Petersen and H. A. Shugart, The Nuclear Spins, Hyperfine Structure Separations and Nuclear Moments of Sc^{46} and Y^{91}, Phys. Rev. 128, 1740 (1962).

(b) W. B. Ewbank and H. A. Shugart, Hyperfine Structure Measurements on Silver-105, Phys. Rev. 129, 1617 (1963).

(c) E. D. Commins and D. A. Dobson, Beta-Decay Asymmetry and Nuclear Magnetic Moment of Neon-19, Phys. Rev. Letters 10, 347 (1963).

Also, Barbara M. Dodsworth and D. A. Dobson have prepared theses on their research which permits them to receive degrees in June.

PHYSICS RESEARCH

Wilson M. Powell and Robert W. Birge in charge

INTERACTION STUDIES

A good deal of the effort of the group during this period was devoted to constructing a 700-MeV/c separated K^+ beam for use with the 30-inch heavy liquid bubble chamber. The experiment done as described below involved looking for the rare four-body decay mode: $K^+ \rightarrow \pi^+ + \pi^\pm + e^\pm + \nu$. This process occurs about 1 in 10^4 ordinary decays and necessitated stopping 2 to 3×10^6 K^+ in the chamber. Although the experiment was the first on the Bevatron after the 7-month shutdown, and in spite of the fact that three experiments were run simultaneously, the machine operated so well that the run progressed exactly on schedule. By the end of April 200,000 pictures had been taken.

Experimental Study of K^+_{e4} Decays

(done in collaboration with U. Camerini, W. F. Fry, J. Gaidos, and R. H. March, University of Wisconsin, and S. Natali, Universitá di Bari, Italy)

The rare mode of decay K_{e4} can be used to test the selection rule $\Delta S = \Delta Q$ for the axial vector currents. The decay mode

$$K^+ \rightarrow \pi^+ + \pi^+ + e^- + \bar{\nu} \qquad (1)$$

is forbidden, while

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

is permitted by the selection rule. Vector currents can occur in the decay (2) but are probably inhibited. Since the selection rule was found not to be valid in K^0_{e3} decays for vector currents, it is of considerable interest to test the rule for axial vector currents.

The rate of the K_{e4} decay has been estimated by Mathur[1] and by Chadan and Oneda.[2] An example of such a decay in emulsion has been reported by Koller et al.[3]

The Berkeley heavy liquid chamber, filled with freon (C_3F_8), was exposed to a stopping K^+ beam from the Berkeley Bevatron. A total of 250,000 pictures was taken, of which about 50,000 have been scanned for tau decays and "K_{e4} like" events. Eleven K_{e4} decays have been observed together with 28,000 τ decays. From these numbers we estimate that the partial decay rate into the K_{e4} mode is $(2 \pm 0.6 \times 10^3)$ decays/sec, which is

1. V. S. Mathur, Nuovo Cimento 14, 1322 (1959).
2. K. Chadan and S. Oneda, Phys. Rev. Letters 3, 292 (1959).
3. E. L. Koller, S. Taylor, T. Heutter, and P. Stamer, Phys. Rev. Letters 9, 328 (1962).

$(2.3 \pm 0.7 \times 10^{-5})$ of the total decay K^+ decay rate. This is consistent with theoretical estimates for the K_{e4} rate. The error is only statistical. The systematic error due to scanning inefficiency for the K_{e4} events may be as large as 30%.

All of the 11 K_{e4} decays are of the mode $K^+ \rightarrow \pi^+ + \pi^- + e^+ + \nu$, which corresponds to the conservation of the $\Delta S = \Delta Q$ selection rule. If the $\Delta S = \Delta Q$ amplitude were the same for axial vector as for vector currents, then we should have seen three events of the type $K^+ \rightarrow \pi^+ + \pi^+ + e^- + \bar{\nu}$ in the sample scanned to date.

Beta Decay of the Lambda

Robert P. Ely, George Gidal, George E. Kalmus, Wilson M. Powell, and W. J. Singleton

The scanning of the stopping K^- film for Λ_β decays has been completed. A total of 192,000 Λ decays of the type $\Lambda \rightarrow p + \pi^-$ were found. The number of beta decays of the Λ, $\Lambda \rightarrow p + e^- + \bar{\nu}$ found was 150.

A value of $(0.82 \pm 0.13) \times 10^{-3}$ was obtained for the branching ratio $R = \frac{\Lambda \rightarrow p\, e^- + \bar{\nu}}{\Lambda \rightarrow N + \pi}$.

A paper on this work has been accepted for publication.[4]

Analysis of the Λ beta decays is continuing in order to obtain angular correlations between the decay products.

Groups from the University College, London, and the University of Colorado are participating in this work.

π^+-p Scattering at 600 MeV

Peter Newcomb

This experiment has been completed. A thesis (UCRL-10563) and a Physical Review paper (UCRL-10682) are being prepared.

Pion-Pion Resonances

Robert W. Birge, Zaven Guiragossian, and Wilson M. Powell

A report has been submitted to the Physical Review: Zaven G. T. Guiragossian, Study of Pion-Pion Resonances in 3.3-BeV/c π^--p Interactions (UCRL-10730, May 1963).

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4. Robert P. Ely, George Gidal, George E. Kalmus, Larry O. Oswald, Wilson M. Powell, William J. Singleton, Frederick W. Bullock, Cyril Henderson, David J. Miller, and F. Russell Stannard, The Beta-Decay Branching Ratio of the Lambda Hyperon, Phys. Rev. (to be published).

D-D Interactions at 3.7 BeV/c

Preliminary tuning was done at Brookhaven with the help of Hugh Brown to find the conditions and flux of deuterons down the 3.7-BeV/c separated beam channel for use with the 20-in. deuterium chamber.

K^+-p Elastic Scattering at 910 MeV/c; Polarization of the Recoil Protons

Warner Hirsch and George Gidal

The experiment is now almost completed. A ten-minute paper (UCRL-10768) describing near-final results was given at the New York meeting of the American Physical Society in January, 1963. Since that time processing, editing, and selecting of events for the angular distribution and the polarization determination have been completed. A final result on 1154 events shows that the expression

$$\frac{d\sigma}{d\Omega} \propto 1 + (0.18 \pm 0.05) \cos \theta_k^{cm}$$

can fit the data. The following final polarization values were obtained:

for $40° \leq \theta_k^{cm} < 70°$, $\bar{P}(\theta_k^{cm}) = -0.80 \pm 0.80$,

for $70° \leq \theta_k^{cm} < 100°$, $\bar{P}(\theta_k^{cm}) = -0.74 \pm 0.45$,

for $100° \leq \theta_k^{cm} < 140°$, $\bar{P}(\theta_k^{cm}) = +0.55 \pm 0.93$,

and for $140° \leq \theta_k^{cm} < 161°$, $\bar{P}(\theta_k^{cm}) = +0.70 \pm 0.93$.

Phase-shift analysis has proceeded almost to completion, with the above polarization data used in an attempt to restrict the number of solutions. A paper on this experiment is currently being written (UCRL-10813).

The Branching Ratio for $\Lambda \to p + \mu^- + \bar{\nu}$ Decay

Anne Kernan, Carl L. Sandler, and Wilson M. Powell

A preliminary estimate of $R_\mu = \frac{(\Lambda \to p + \mu^- + \bar{\nu})}{(\Lambda \to \text{all modes})}$

has been obtained from a study of 100,000 Λ decays in the charged mode:

$$R_\mu \leq (0.3 \pm 0.2) \times 10^{-3}.$$

A final estimate, derived from 190,000 visible Λ decays, will be published shortly.

This research is being performed in collaboration with a group at University College, London.

CHAMBER IMPROVEMENTS

Wilson M. Powell and Larry Oswald

The depth of the 30-inch propane chamber has been doubled to 12 in., and the magnetic field has been raised from 13,000 to 15,000 G by putting the coils of the magnet closer together. A radically new illumination system has been constructed. This uses external lights, and a sheet of "Scotch Lite" beaded reflective sheeting of very high quality and imperceptible grain as a reflector under the chamber. Photographs of superior resolution can be made of tracks with bubble images 14 μ wide on the film corresponding to 100 μ in the chamber. The background is completely free from blemishes except for the overlap edge (a single straight line) near the center of the chamber.

DATA REDUCTION

Robert W. Birge and Paul W. Weber

With a total effort of 11 (full time equivalents) visual measurement personnel, the following data reduction was accomplished in the past six months.

Scanning

Experiment	Bubble chamber	Beam	Number of frames
16	30-inch Propane	1.15-BeV/c K^-	14,950
20	30-inch Propane	800-MeV/c K^+	127,490
23	30-inch Propane	4.50-MeV/c K^- (stopping)	65,230
26	72-inch Hydrogen	1.17-BeV/c π^-	2,500
28	30-inch Freon	4.50-MeV/c K^+ (stopping)	10,730
		Total	220,900

Measuring

Equipment	Measuring hours	Number of vertices	Rate vertices measuring hours	Capacity 4032 measuring hr (%)
Microscope C	560.1	2633	4.70	13.9
MP - 1C	600.4	2404	4.00	14.9
Microscope E[a]	944.0	5349	5.67	23.4
Total	2104.5	10,386	Average 4.94	17.4

[a]Converted to a three-view measuring instrument in April 1963.

The new three-view scanner and one SPVA scanner are being used to scan the new 70-mm and 46-mm film.

PHYSICS RESEARCH

Emilio Segrè and Owen Chamberlain in charge

SCATTERING EXPERIMENTS WITH A POLARIZED PROTON TARGET

John Arens, Frederick Betz, Owen Chamberlain, Byron Dieterle, Helmut Dost, Claude Schultz, Gilbert Shapiro, Wladyslaw Troka, and Ludwig Van Rossum

Using the same crystalline material as reported previously--lanthanum magnesium double nitrate [$La_2Mg_3(NO_3)_{12} + 24\ H_2O$] that has been doped with 1% neodymium-142--proton polarizations have been maintained between 25% and 30% with the existing equipment. The weight of the crystal is 28 grams, 3% of which is hydrogen in the water of crystallization.

Experiments with a smaller crystal, using a microwave generator at 74 kMc/sec, have shown that it is possible to achieve proton polarizations of at least 65% to 70%. We are awaiting the arrival of a new microwave generator (the present equipment operates at 35 kMc/sec) which will put out, in the 70-kMc/sec region, sufficient power to polarize the large sample. It is expected that the proton polarization will then approximate that achieved with the small sample.

Since the crystal used for proton polarization contains such a large proportion of heavy elements, it is necessary in most experiments to make a kinematic separation of the two-body scattering events from the free protons. It was deemed advisable to make a trial run to see how well such a separation could be made.

The experiment selected for this trial run was the elastic scattering of π^+ mesons from hydrogen. It was found that a satisfactory separation can be made. When pion and proton are detected in coincidence, the hydrogen events outnumber the background by a factor of ≈ 1.5. When it is not possible to detect the recoil proton because its energy is too low, it is still possible to identify hydrogen events by requiring scattered pions (at a given angle) to have the proper range to suit two-body kinematics. Under these circumstances, the true signal-to-background ratio is 1 to 4. It has been possible to identify the hydrogen events, even when the recoil particle energy is as low as 20 MeV.

Meaningful results were obtained in this experiment. The polarization parameter P, which is usually measured by analysis of the recoil proton, was determined. The results are in agreement with calculations based on phase shifts interpolated from those obtained at neighboring energies.

μ^- CAPTURE IN He^3

Leonard Auerbach, Robert Esterling, Roger Hill, David Jenkins, Joseph Lach, and Norman Lipman

A measurement of μ^- capture in He^3 was successfully concluded in April 1963 (see Fig. 1). A high-pressure He^3 scintillation counter served as target and detector for the capture process $\mu^- + He^3 \rightarrow H^3 + \nu$. The

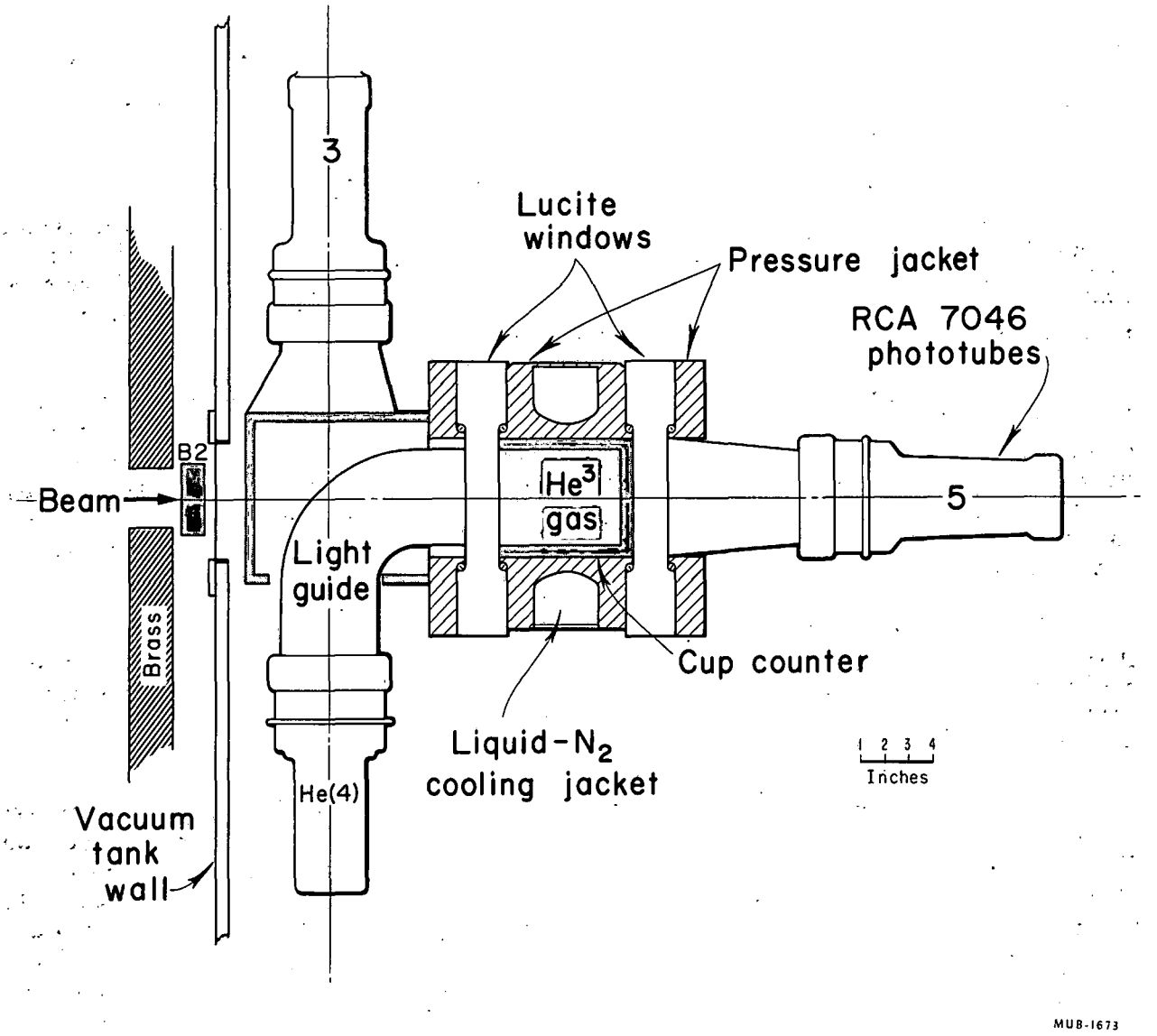

Fig. 1. A typical pulse-height spectrum from the He^3 scintillator showing the 1.9-MeV triton recoil peak. The low-energy tail is a result of μ to e decays that miss the veto counters.

process was recognized by the emission of a monoenergetic triton (1.9 MeV) which travels only 1.5 mm in the He^3 gas. The main background was from the normal μ-e decay which occurs 300 times as frequently. However, the decay electrons being minimum ionizing lose less than 0.5 MeV in the gas, and most of them are vetoed electronically by a cup counter which surrounds the gas.

The experiment measures the fraction of stopped muons, which gives the capture process (F_c), and, knowing the decay rate (Λ_d), one deduces the capture rate in He^3 ($\Lambda_c^{He^3}$). The quantities measured in the experiment are the number of triton recoils of 1.9 MeV, and the number of muons brought to rest in the gas. Both numbers are subject to edge-effect corrections of 2% (e.g., some μ's stop elsewhere than the gas, but are not vetoed). Such effects have been measured experimentally in a series of correction runs with He^4 gas, Xe gas, and nuclear emulsions put in the place of the He^3.

The muon capture rate in He^3 has been calculated on the basis of "universality" of the weak interactions, using the coupling constants measured from β decay, and making corrections for several strong interaction effects.[1] The capture rate predicted by Wolfenstein[2] is 1450/sec, with a present theoretical uncertainty which may be as high as 10%.

We have obtained 40,000 capture events, taken under various experimental conditions to reduce systematic errors. Although the analysis of the data has not been completed, a capture rate can be given:

$$\Lambda_c^{He^3} = 1500 \pm 50/\text{sec};$$

the error is expected to be reduced by one-half when the analysis is completed.

This rate should be compared with the earlier experiment of Falomkin, et al.,[3] made with a He^3 diffusion chamber in which only 200 events were obtained, giving a capture rate of 1410 ± 140 sec^{-1}. The results agree with the theoretical prediction within the present uncertainties of $\approx 10\%$ and thereby verify the Universal Fermi Interaction (UFI) to this accuracy. In effect, the experiment shows $g_{\beta\ \text{decay}} = g_{\mu\text{capture}}$ to 5%. Measurements of μ capture in hydrogen test UFI to a similar accuracy, but the experimental and theoretical problems in this case are of a different nature. With our new experiment on μ capture in He^3 the experimental accuracy is now much better than the theory; however, there is hope that a more complete calculation will improve the theoretical accuracy to 5% or better in the near future.[2]

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1. L. Wolfenstein, in Proceedings of the 1960 Annual International Conference on High Energy Physics at Rochester (Interscience Publishers, Inc., New York, 1960), p. 529. L. Wolfenstein, Proceedings of International Conference on High Energy Physics, CERN, July 1962 (CERN, Geneva, 1962) p. 821.

2. This rate makes use of the latest He^3 rms radius (an average of $r_{magnetic}$ and $r_{electric}$ is taken), L. Wolfenstein private communication, May 1963.

3. I. V. Falomkin, A. I. Filippov, M. M. Kulyukin, B. Pontecorvo, Yu. A. Scherbakov, R. M. Sulyaev, V. M. Tsupko-Sitnikov, and O. A. Zaimidoroga, Phys. Letters 3, 229 (1963).

EFFECTS OF THE SINGLE-PION EXCHANGE IN THE REACTION $p + p \rightarrow n + p + \pi^+$

Joseph Lach, Leonard B. Auerbach, Thomas Elioff,
William B. Johnson, Clyde E. Wiegand,
and Tom Ypsilantis

With the same scintillation counter array[4] that was used to study the reactions $\pi^\pm + p \rightarrow n + \pi^\pm + \pi^\pm$, a measurement is made of the distribution in energy and angle of neutrons from the reaction $p + p \rightarrow n + p + \pi$ at an incident proton momentum of 2.5 BeV/c. The coordinates of the three final-state particles are measured by this array of plastic scintillation counters, the energy of the recoil neutron being determined through its flight time. The range of measured neutron angles is limited to 4 to 60 deg, and the range of recoil momentum is from approximately 150 to 330 MeV/c. Data are recorded on magnetic tape in a format directly acceptable to an IBM 7090 computer where sorting and kinematical fitting are done.

A Monte Carlo computation is made in which the effects of the complex resolution functions of the apparatus and the fitting code are investigated and used to compute the overall efficiency and resolution of the apparatus. We have restricted our analysis to a region of θ^*, the pion-proton scattering angle measured in their rest frame relative to the incident proton and bounded by $-0.5 < \cos(\theta^*) < +0.5$; this restriction results from the geometrical limitations of the angular region in which the final-state pion and proton could be detected, and from our inability to distinguish between them in 18% of the events. Comparisons with other experiments[5, 6] and predictions of the one-pion-exchange model are made. A Chew-Low[7] extrapolation is performed and deviations from a linear extrapolation are found. The peripheral model predictions by Selleri[8] agree well with the observed position and reasonably well with the observed shape of the 3/2, 3/2 resonance if an integration is made over momentum transfer. The cross section, as a function of momentum transfer, deviates from the predicted behavior.

A detailed report of this experiment is given elsewhere.[9]

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4. Physics Division Semiannual Report, UCRL-9215 (June 1960) p. 31.
5. G. A. Smith, H. Courant, E. Fowler, H. Kraybill, J. Sandweiss, and H. Taft, Phys. Rev. Letters 5, 571 (1960).
6. W. J. Fickinger, E. Pickup, D. K. Robinson, and E. O. Salant, Phys. Rev. 125, 2082 (1962).
7. Geoffrey F. Chew and F. E. Low, Phys. Rev. 113, 1640 (1959).
8. F. Selleri, Phys. Rev. Letters 6, 64 (1961).
9. Joseph T. Lach, Effects of the Single Pion Exchange in the Reaction $p + p \rightarrow n + p + \pi^+$ (Ph. D. Thesis), UCRL-10718, March 1963.

K^+p INTERACTION AT 1.96 BeV/c

William Chinowsky
(in collaboration with Gerson Goldhaber, Sulamith Goldhaber, Thomas O' Halloran and Betram Schwarzchild of Trilling-Goldhaber Group)

The analysis of the photographs from the Brookhaven 20-inch liquid hydrogen bubble chamber is continuing.[10] All film has been scanned twice and some 90% of the events have been measured. Analysis of approx 2/3 of these (≈ 1200 events) has yielded the following preliminary results.

(a) Cross sections

Reaction	Cross section (mb)
$K^+\pi^-p\pi^+$	1.7 ± 0.2
$K^0\pi^0p\pi^+$	1.3 ± 0.2
$K^0\pi^+n\pi^+$	0.3 ± 0.1
$K^+\pi^+n\pi^0$, $K^+\pi^0p\pi^0$	≈ 0.2
$K^0\pi^+p$	4.6 ± 0.6
$K^+\pi^0p$	2.0 ± 0.3
$K^+\pi^+n$	1.6 ± 0.3
K^+p	7.6 ± 1.0
$K^0p\pi^+\pi^+\pi^-$	0.4 ± 0.02
$K^+K^+\Lambda$	$\lesssim 0.01$

and

$\sigma_{total} = 19.4 \pm 2.1$ mb.

(b) Differential elastic scattering distribution

The angular distribution of elastic scattering in the c.m. system shows the characteristic forward angle diffraction peak. The data are well represented by the function

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_0 e^{At} ,$$

where t is the square of the four-momentum transfer given by $t = -2p^2(1-\cos\theta)$, with p the c.m. momentum and θ the scattering angle of the K^+.

10. Some details of the exposure and relevant references are given by W. Chinowsky et al., Phys. Rev. Letters 9, 330 (1962).

A least-squares fit to the observed distribution of ≈600 events yields

$$\frac{d\sigma}{d\Omega_0} = 5.1 \pm 0.4 \text{ mb/sr},$$

$$A = 2.8 \pm 0.2 \text{ BeV}^{-2}.$$

(c) Inelastic processes

Analysis of the inelastic events is discussed in the report of the Trilling-Goldhaber Group elsewhere in this document.

GAS SCINTILLATION COUNTER

Robert Esterling and Norman Lipman

A gas scintillation counter[11] which operates at liquid nitrogen temperature, and at pressures of up to 31 atm, has been developed with the help of the target engineering group. The gas used was He^4 and later He^3. In view of the high cost of He^3 ($0.20 cc of gass at NTP) very careful design was required to keep gas leakage rates at a very low level. Most gasket materials were ineffective at liquid nitrogen temperatures, but a successful design was achieved using Kel-F O rings and a window shape such that the lucite window tightened against the O ring and improved the seal as the counter was cooled down. At maximum pressure the leakage rate was less than 1 cc NTP per month. The behavior of the counter was measured under various conditions. Several types of reflector coating and of wavelength shifter were tried, and the effects of impurities and of absolute gas pressure on the output pulse height were measured. Optimum conditions included a wall coating of 1 mg/cm^2 of MgO covered by 50 μg/cm^2 of diphenyl stilbene wavelength shifter, gas purity better than 1 in 10^5, and a working pressure of 245 to 445 psig. At lower pressures the pulse height dropped. The pulse height varied linearly with energy lost in the gas. The response throughout the 1-liter volume was constant to ±5%, and the pulse-height resolution for 5.43-MeV α particles was 13% full width at half maximum. Figure 2 shows how this counter was incorporated in a target assembly used for the measurement of the μ^- capture rate in He^3 and He^4.

11. R. E. Shamu, Nucl. Instr. Methods 14, 297 (1961) (see for references).

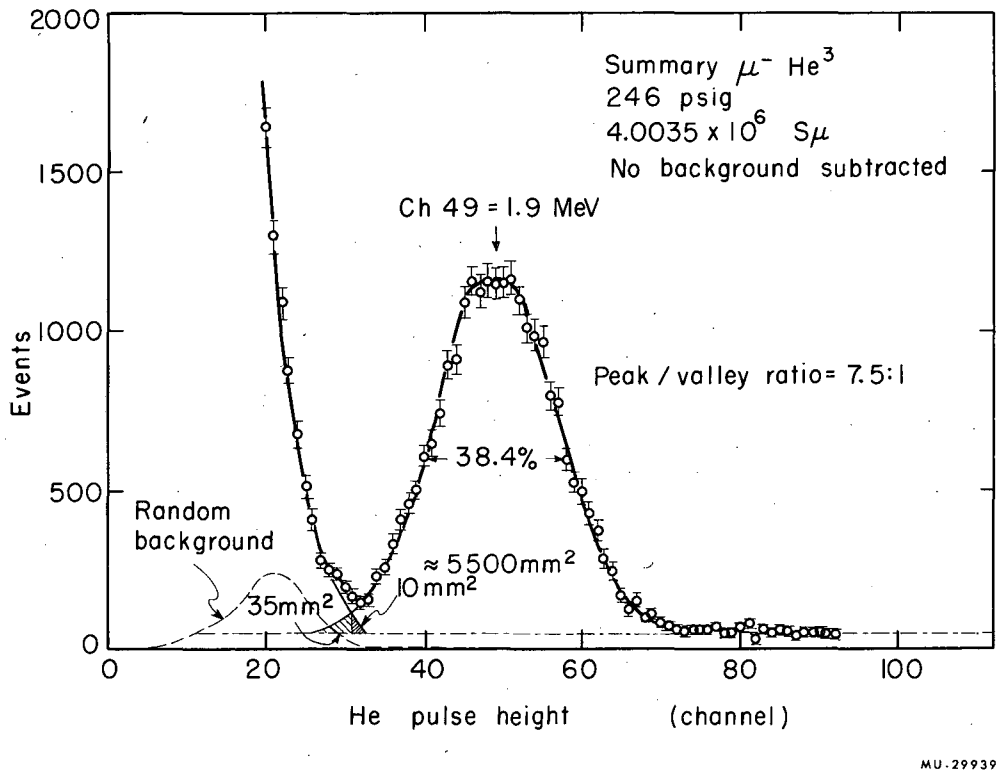

Fig. 2. The incorporation of the gas scintillation counter operating at liquid nitrogen temperature and pressures up to 31 atm into a target assembly used for the measurement of the μ^- capture rate in He^3 and He^4.

PHYSICS RESEARCH

George H. Trilling and Gerson Goldhaber in charge

EVIDENCE FOR VECTOR MESON EXCHANGE

Sulamith Goldhaber, Gerson Goldhaber, and Thomas O' Halloran
(in collaboration with W. Chinowsky of the Segrè-Chamberlain group)

We have continued the investigation of the K^+p interaction leading to three particles in the final state (inelastic pion production). The single pion production leads to the following three charge states:

	Cross section, σ (mb)	
$K^+ + p \rightarrow K^0 + \pi^+ + p$	4.6 ± 0.6	(1)
$K^+ + p \rightarrow K^+ + \pi^0 + p$	2.0 ± 0.3	(2)
$K^+ + p \rightarrow K^+ + \pi^+ + n$	1.6 ± 0.3	(3)

The interaction leading to reactions (1) and (2) can proceed either via $K^* + N$ production or via $K + N^*$ production. Reaction (3), however, can only proceed via $K + N^*$ production. The events contributing to reaction (1) come from two sources, from events with charged K_1^0 decay modes (311 events) and from events with neutral K_1^0 decay or K_2^0 mesons. Of the latter we have completed only a partial sample (173 events). The charge states (1) and (2) show both the K-π and N-π resonances in the Dalitz plot. Charge state (3) has only a few events and shows very little enhancement in the N^* band. These results are consistent with the expected intensity ratio of $N^{*++}(\pi^+p):N^{*+}(\pi^0p):N^{*+}(\pi^+n) = 9:2:1$.

Both resonances are produced peripherally and may thus proceed via a one-particle exchange mechanism. The four-momentum transfer squared, Δ_2^2, associated with N^* production has a considerably wider distribution than Δ_1^2, the four-momentum transfer associated with K^* production. In terms of a one-particle exchange model this difference is indicative of the exchange of a heavier particle for N^* production. For N^* production one-pion exchange is forbidden because of parity considerations at the K^+-K^0 vertex. The lightest single-particle exchange allowed is that of the ρ meson. The exchange of a spin 1 particle (ρ meson) now permits some angular information to be transmitted along the direction of the exchange particle. Indeed, we find strong deviations from isotropy in the distribution of Φ, the Treiman-Yang angle for this reaction (see Fig. 3). We have fitted the distribution in an expansion $f(\Phi) = a + b \cos\Phi + c \cos^2\Phi$ with coefficients $a = 5.0 \pm 0.4$, $b = -0.4 \pm 0.25$, and $c = -3.0 \pm 0.6$. We note that the coefficient b is small, i.e., the interference term is small, and that c is negative. The distribution is thus well represented by the form $f(\Phi) = \alpha + \beta \sin^2\Phi$, with $\alpha = 2.0 \pm 0.5$ and $\beta = 3.0 \pm 0.6$.

For the reaction producing the K^* resonance, i.e., $K^+ + p \rightarrow K^{*+} + p$, pion exchange is allowed. A spin flip of the proton at the $p\pi p$ vertex is required, since the exchange pion is emitted in a p-wave state, which introduces a γ_5 into the transition matrix.

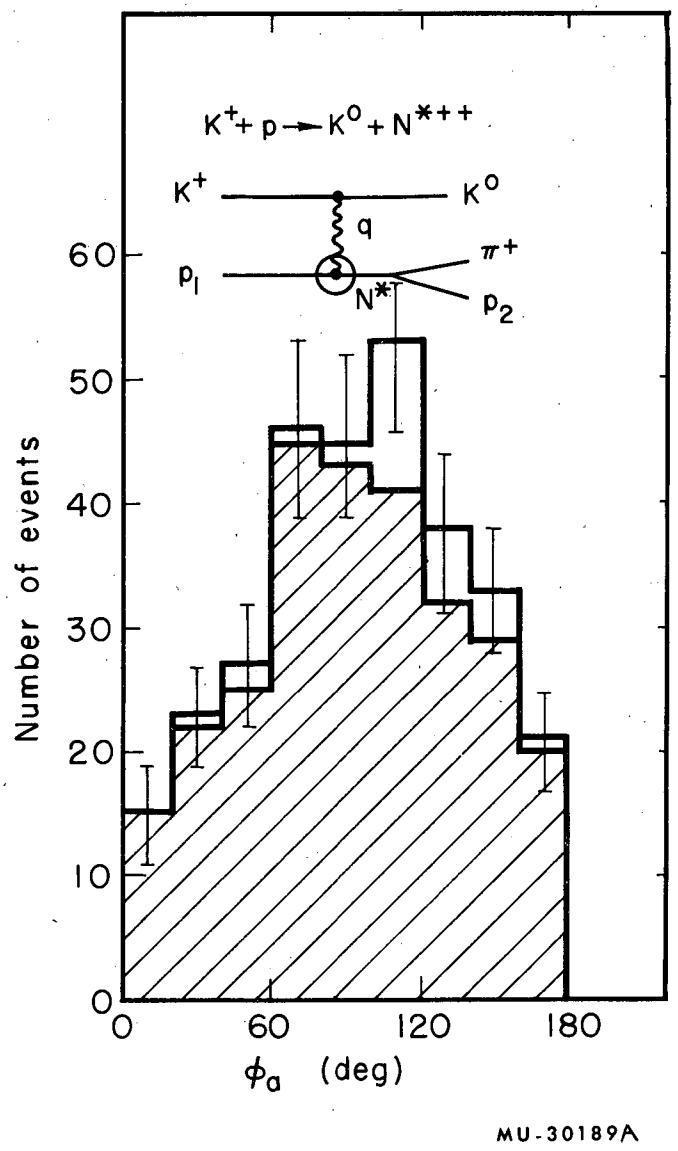

Fig. 3. The Treiman-Yang angle distribution for the reaction $K^+ + p \rightarrow K^0 + N^{*++}$.

In principle one might thus expect alignment of the K_{in} - K_{out} scattering angle with $m(K^*) = 0$ similar to that observed in the K^* produced in the double resonance events. The distribution, however, is in essence isotropic, with a possible small contribution of $\sin^2\theta$. A possible explanation of this distribution is that both pion and ρ (or ω) exchange contribute to the interaction.

Here we are using the alignment of the K^* spin with respect to the exchange particle axis as a probe for the exchange of a spin-zero meson. In the distribution of the Treiman-Yang angle for the K^* production, we also note a small deviation from isotropy, although the effect is not as large as that for N^* production. Here too the deviation from isotropy may again be due to both π and ρ (or ω) exchange participating in the interaction.

π^-p INTERACTIONS AT 3.65 AND 3.85 BeV/c

John L. Brown, Gerson Goldhaber, Sulamith Goldhaber, John Kadyk, Thomas O' Halloran, Bertram Schwarzschild, Victor Seeger, Benjamin Shen and George Trilling

In collaboration with the Alvarez Group, we used a part of the beam components being set up for the 3-BeV/c K^- run to provide beams of negative pions of various momenta in the 72-inch bubble chamber. We have obtained about 35,000 pictures at 3.65 BeV/c, and 65,000 pictures at 3.85 BeV/c.

The data at the lower momentum will be used to provide a detailed comparison with our results for π^+-p interactions at just the same energy. At the higher momentum, our major interest is the study of the production and properties of strange-particle resonant states. The analysis of these photographs is just getting under way, and there are as yet no results.

THE STUDY OF THE π^+p INTERACTION AT 3.65 BeV/c

John L. Brown, Gerson Goldhaber, Sulamith Goldhaber, John Kadyk, Victor Seeger, Benjamin Shen, and George Trilling

We have obtained a run consisting of 50,000 pictures from the Brookhaven National Laboratory 20-inch hydrogen bubble chamber exposed in the Brookhaven-Yale beam, which was tuned to π^+ mesons of 3.65 BeV/c. We have concentrated on the reactions

$$\pi^+ + p \rightarrow \pi^+ \pi^- p \pi^+ \qquad (1)$$

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

$$\rightarrow \pi^+ \pi^- \pi^+ n \pi^+, \qquad (3)$$

and to date have identified 671, 761, and 143 events for these three reactions, respectively.

In reaction (1), 410 events fall in the N^* band defined by $1130 \leq M\pi^+p \leq 1300$ MeV and 418 events in the ρ band defined by $675 \leq M\pi^+\pi^- \leq 875$ MeV. Of these, 155 events correspond to double resonance production. The ρ-N^*

events are consistent with peripheral production and the ρ is formed in an aligned state.

In reaction (2), 603 events fall in the N^* band and 175 events in the ω band defined by $770 \leq M\pi^+\pi^-\pi^0 \leq 800$ MeV. About 1/2 the ω's produced are made in the double resonance.

A search for ϕ events and other strange-particle production and a detailed study of the various processes involved, are in progress.

DATA HANDLING

Howard S. White in charge

FOG-CLOUDY-FAIR PROGRAM

Program Development

FOG

The FOG programs were extended to make an optional calculation for electron tracks by use of the Behr-Mittner procedure for fitting momentum. This procedure yields the best estimates of kinematical parameters for electron tracks. The method has been applied to several hundred events measured in the 30-inch propane bubble chamber and has demonstrated improved parameter estimates.

To accommodate the revised 30-inch propane bubble chamber film format generated by the new camera and chamber optics, several changes were made in the FOG program. These included (a) provisions for identification by roll and frame as well as by picture number, (b) an entirely new set of optical and magnetic-field constants, and (c) an input merging and sorting program to fit the Franckenstein measurements into the natural order of the new film format.

Evaluations of constants appropriate for the 20-inch hydrogen bubble chamber at Brookhaven and for the 80-cm propane bubble chamber at Ecole Polytechnique were completed. Improved values of constants for the 72-inch hydrogen bubble chamber have been placed in the program.

Assembly and debugging of the FOG program was completed in a form suitable for multi-programmed use with HAZE. To determine relative ionization of tracks for later use in the kinematic-analysis programs, the FOG program will also make use of ionization measurements produced by the flying-spot-digitizer (FSD).

The sections of the FOG-CLOUDY-FAIR Reference Manual[1] describing these programs have been completed and issued.
(Shirley Buckman and Barbara Ripple)

CLOUDY

The CLOUDY programs were extended to accommodate experiments in deuterium by allowing multiply charged particles to be included within the program's quantum conservation rules.

Modifications necessary to handle the identification parameters used for the revised 30-inch propane bubble-chamber data were incorporated into the programs.

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1. FOG-CLOUDY-FAIR, Data Processing System Reference Manual, Data Handling Group, UCID-1340.

To allow for greater flexibility in the computational procedure, modifications were made to the way in which various constraints can be specified. These include provisions for the performance of several independent constraining processes before they reach an output threshold, together with a more general handling of singular constraints classes so that, for example, secondary two-prong scatterings can be tested for elasticity; if this test is satisfied, the improved paramters are used in the primary constraint, while unimproved parameters are left for use in the primary constraint if the secondary scattering does not fit the elastic case. Additional improvements were made in the handling of "Zero-C" calculations, so that we can more satisfactorily express the angular errors of incoming particles going to decay vertices.

Automatic calculation of the beam track's momentum at a stated reference plane (thin window) was added to allow simpler beam-momentum calibrations and checks.

The programs were modified to allow a variety of assignment-list classifications (event types) on one magnetic-tape library.

Sorting, merging, and decollating programs were written to facilitate CLOUDY library maintenance in conjunction with the FSD system.

Sets of constraints specifying calculational procedures for several new experiments were written. These experiments include double-hyperon production in deuterium, ρ resonances produced by K^- particles in hydrogen, deuteron-deuteron reactions in the 20-inch Brookhaven deuterium chamber, and decay processes of low-energy K^- mesons in Freon.
(Dennis Hall and Vivian Morgan)

FAIR

A revised FAIR program to produce event listings was made operational and put into production for all new data classes. As well as producing a more complete parameter listing, this program can be controlled by a FAIR selection tape to give detailed listings only of selected events chosen by their parameter values. For example, it is possible to define a standard set of parameter values and to request the complete parameter listing only for events not lying within the standard set.

Debugging of extensions to the abstraction program was continued. This program can now perform mass permutation, topology, and chain-level selection in both modes. The two selection modes are (a) comparison of parameters to prespecified ranges to define acceptance, and (b) comparison of individual parameters between various mass permutations and versions to choose one of several alternative hypotheses concerning an event. The new assembly includes an expanded master dictionary that recognizes the symbolic names of all parameters contained on CLOUDY libraries.

The listing and display program extension also continued. This new assembly provides improved flexibility in making cathode ray tube (CRT) histograms and scatter diagrams, together with the ability to generate the previously described tape that controls the page listing program.

The present program status allows one to use a truly associative information-retrieval system for events contained on CLOUDY library tapes. This powerful technique allows us to describe events of interest in terms of their significant parameters, to retrieve them automatically, and to study their properties without having to select data manually.

Since the FAIR system is effectively a specialized compiler for data summarization, it is expected that the physicist will be writing in the FAIR source language more and more when analyzing his data. Work is therefore progressing on a user's manual.
(Dennis Hall, James Haug, and Loren Shalz)

Data Processing Operations

The following tabulation shows the number of events processed through various phases of the system. The significantly decreased number of events processed during this period is due to a corresponding drop in the number submitted by the Powell-Birge group, and is attributed to exhaustion of data obtained before the Bevatron shutdown, together with diversion of scanning and measuring personnel in preparation for new Bevatron runs late in the reporting period.

Conventional processing

Exp.	FOG origins reduced	CLOUDY events processed		FAIR events abstracted	
16	873	AW01-05	650		
		WP-03	1136		
		YP02-03	1538		
20	1785	CW-01	22		
		GG-02	1308	GG-02	758
		JG01-02	278		
		UC-01	681	UC-01	681
		WH-01	196	WH-01	196
20H	5	WP-20	5		
23	7948	WP-08	2184	WP-08	2107
23H	3562	WP-13	789	WP-13	796
		WP-15	429	WP-15	531
		WP-19	399	WP-19	399
25	762	TS01-02	687	TS01-02	758
26	517	RB01-04	155	RB-01	47
27	847	SK01-05	123		
98	1944	WF01-06	316		

THE FLYING-SPOT DIGITIZER (FSD) SYSTEM

Hardware Development

The FSD device became completely operational during the period of this report. Complete control by the computer is possible, making film positioning, stage positioning, and selection of operation mode and speed entirely automatic. Measurement of events in both the 0° and 90° scan modes was routinely accomplished. Extensive modifications to the electronics significantly improved reliability and improved precision. We discovered that the 60-cycle servosystem controlling the stage motion caused mechanical vibrations within the device; it was therefore replaced by a dc servosystem.

Some work remains to be done in completing the mechanical hardware. Since this does not prevent useful operation of the device, the work has been delayed until the expected 7090 computer shutdown in June 1963 in order to produce the least disruption to operations. At that time the sheet metal covering will be completed, the operator's console installed, and the utilities systems reinstalled into a centralized cabinet.

Satisfactory operation of the first SPVB (roadmaking scanning projector) was achieved during this period. All features of the final machine have been made operational except automatic frame-number readout. Much work was devoted to improving reliability of the electronics, and significant gains were observed.

Three additional scanning projectors for use with the system were largely completed during this period. These, plus the prototype, will yield a system capability of approximately 250,000 bubble chamber events per year when they become operational in July 1963.

Slight modifications are being made to allow the system to operate with film from other laboratories, so that in the near future we can process Brookhaven 20-inch and 80-inch hydrogen bubble chamber film as well as that from the LRL 72- and 25-inch hydrogen and 30-inch propane bubble chambers.
(Jack V. Franck and Howard S. White)

HAZE Program Development

Extensive modifications have been made to the main FSD program, HAZE.

Debugging of a new fiducial-point searching subroutine was completed. This routine can locate in the 72-inch hydrogen bubble-chamber film both of the fiducial marks making roads for 95% of the events and at least one fiducial mark making a road for 99.9% of the events. In the latter case, mechanical film positioning is relied upon for road overlay.

Constants required for accurate transformations between scan table and FSD systems were determined and the program was modified to use these constants.

All logical changes in the program to handle the orthogonal mode of FSD scanning have been made and are debugged. To complete the changes for use of orthogonal scans, a new output subroutine is being written that will match the several possible scans of each track.

A modification has been made to write a special output tape during the running of HAZE. This modification is on a sense-switch option. A new program reads this tape and produces a diagnostic consisting of a printout of the histogram made by the filter section of HAZE and pages of related information. Use of these diagnostic programs has greatly facilitated the debugging and improving of the filtering routines.

The filtering section of HAZE was reorganized and essentially rewritten. It is debugged and is working successfully.

The scan-tape editing program has been reassembled and has been successfully processing scan-table output.
(Dennis Hall, Carol Osborne, Joan Stekler, William Thompson, and Howard White)

Digital Automatic Pattern Recognition (DAPR) Program Development

The Digital Automatic Pattern Recognition program for bubble-chamber film demonstrated significant gains during this period. Prototype programs have been written which have successfully followed most beam tracks within the 72-inch hydrogen bubble chamber. These programs process data from the FSD at a rate of approximately 10,000 digitizings per second on the IBM 7090. This rate corresponds to the reduction of a complete stereo triad each 10 to 15 sec in the IBM 7094.

During this period, several parts of the beam-track-following program were written and debugged: (a) the fiducial search routine based upon the successful histogramming technique developed for HAZE; (b) a new method to initialize beam tracks which is much faster than previous techniques; (c) a more adequate routine for handling crossing-beam tracks; and (d) an improved shear-table generating program.

A relatively independent program specifically designed to initialize and follow nonbeam tracks is presently being written and debugged.

These programs demonstrate that the procedures for digital pattern recognition are feasible, are of sufficient speed to have adequate capacity for physics use, and are economical in comparison with other techniques.
(Charles Dickens and Mary Downton)

Flying-Spot Digitizer Operation

Actual physics production of events through the FSD system was begun in February. A successful 8-h run which produced 701 events through HAZE, FOG, CLOUDY, and FAIR was made on April 12, 1963. A total of approximately 1500 events had been analyzed by the end of this reporting period. The analyzed events were at first simple two-prong configurations not

requiring the orthogonal scanning mode, were gradually increased in complexity as capabilities were extended, so that by the end of the period, processing included strange-particle events requiring the orthogonal mode.

OTHER DATA HANDLING SYSTEMS

Franckenstein-System Hardware Fabrication

Progress has continued in the fabrication of two new measuring projectors, MPIE and MPIF. Design is completed except for the modifications necessary for Brookhaven film format. Owing to a shortage of shop fabrication efforts, these instruments were not completed during this reporting period, and are presently scheduled for completion during August 1963.

Five scanning projectors (SPVA) have been brought toward completion. Three of these were delivered to physics groups even though final film handling systems were not yet installed. This accelerated delivery provides the research groups with film monitoring capability in time for their scheduled Bevatron experiments. Film handling, including that for Brookhaven film format, is expected to be finished early in the next reporting period.
(Jack V. Franck)

SCAMP Devices for Spark-Chamber Measurement

Design is 95% completed and fabrication 50% completed on two measuring devices for spark chamber film. These instruments were not finished during this reporting period owing to a shortage of shop fabrication efforts, but are scheduled for completion in July 1963.
(Jack V. Franck)

Spark Chamber Automatic Scanning System (SASS)

Preliminary specifications for a completely automatic scanning and measuring system to be used with spark chamber data have been worked out in collaboration with various experimental-physics groups. This system is to initially process film containing images of spark chamber events, and will be capable of measuring to an accuracy of 1 part in 4,000, using open-loop CRT techniques. It will have a capacity for 5 to 30 million events per year. The system will consist of a small digital computer, a specialized CRT unit including a film-transport mechanism, and a computer program that controls the scanning of the film by the CRT. This program will abstract the useful data, and output a magnetic tape containing information in a form similar to SCAMP data for further reduction within a large computer.

Selection of the small computer was nearing completion at the end of this reporting period. Final specifications of the computer's required features had been completed and circulated to 16 different manufacturers. Nine responded with proposals.
(Jack V. Franck, Jerome A. G. Russell, and Howard S. White)

Biological Measurement System (GIBS)

We are planning a device capable of measuring position, size, number, and shape of bacterial colonies contained on agar media. This measurement may be made either directly on Petri dishes themselves, or on a film containing photographic images of the dishes and their colonies. Samples have been mapped with a microdensitometer to determine if characteristic differences in local density within a colony aid in distinguishing it from other colonies having different biological properties.

These studies were made in support of a project headed by Donald Glaser.
(Jerome A. G. Russell)

ACCELERATOR OPERATION AND DEVELOPMENT

BEVATRON

Edward J. Lofgren in charge

The reports for February through April 1962 and May through June 1962 have been issued as Bevatron Operation and Development XXXIII (UCRL-10561, February 12, 1963) and XXXIV (UCRL-10613, April 4, 1963).

Reports XXXV, XXXVI, and XXXVII (for August through October 1962, November 1962 through January 1963, and February through April 1963) have not yet been prepared.

184-INCH CYCLOTRON

Robert L. Thornton in charge
Reported by James T. Vale

An account of work done during this period will be given in the next semiannual report.

88-INCH CYCLOTRON

Hermann A. Grunder in charge

Experimental Facilities

The shielding, beam transport facilities, and power were completed for three additional caves, bringing the number in use to four. Installed equipment includes four scattering experiments, a biomedical facility, and a remote handling system for nuclear chemistry target bombardments.

Beam Development

A number of proton, deuteron, and alpha beams were developed. The beams presently available are summarized in the following tabulation.

Particle	Energy (MeV)	Extraction (%)	Remarks
Proton	25	-	
	50	1.5	Not available externally with present deflector
He^{3+}	25	-	
Alphas (deuterium and H_2^+ of 1/2 α energy)	65	40	20 μA maximum external beam determined by septum heating
	25 to 80	25 to 35	Any intermediate energy available (max. external beam ≈ 0.45 kW)
	130	-	Not available externally

Deflector

Extensive testing was done on the deflector under the supervision of Bob Smith to explore its voltage-holding capabilities and to find ways to increase voltage. A new power supply was installed which delivers less energy to a spark and which has better regulation.

Further information on work done at the 88-inch cyclotron can be found in reports presented to the 1963 International Conference on Sector-Focused Cyclotrons held at CERN, Geneva, April 23-26. These reports are: Bob H. Smith and Herman Grunder, Electrical Design of Electrostatic Deflectors for Sector Focused Cyclotrons, UCRL-10654, March 25, 1963; Bob H. Smith, Deflector Power Supply for Sector-Focused Cyclotrons, UCRL-10655, March 25, 1963; Alper A. Garren and Lloyd Smith, Diagnosis and Correction of Beam Behavior in an Isochronous Cyclotron, UCRL-10756, April 2, 1963; Herman A. Grunder and Frank B. Selph, Operation of the Berkeley 88-Inch Cyclotron, UCRL-10758, April 16, 1963; and Operating Experience with the Berkeley 88-Inch-Cyclotron Electrostatic Deflector, UCRL-10759, April 17, 1963.

HEAVY-ION LINEAR ACCELERATOR

Albert Ghiorso in charge
Reported by Edward L. Hubbard

Material for this section had not been received at the time of publication.

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