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November 1966 thru April 1967

Lawrence Radiation Laboratory
University of California Berkeley

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PHYSICS
Semiannual Report

NOVEMBER 1966 through APRIL 1967

May 1967

LAWRENCE RADIATION LABORATORY
University of California
Berkeley, California

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PHYSICS DIVISION SEMIANNUAL REPORT*

November 1966 through April 1967

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*Preceding Semiannual Reports: UCRL-17282 and UCRL-16863

PHYSICS DIVISION SEMIANNUAL REPORT

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Lawrence Radiation Laboratory
University of California
Berkeley, California

May 1967

GENERAL PHYSICS RESEARCH

PHYSICS RESEARCH

Luis W. Alvarez in charge

Research projects reported below have been carried out by the following (as indicated by the initials at the end of each report): Maris A. Abolins (MAA), Margaret Alston-Garnjost (MAG), Luis W. Alvarez (LWA), Jared A. Anderson (JAA), Roger O. Bangerter (ROB), Angela Barbaro-Galtieri (ABG), J. Peter Berge (JPB), Sharon Buckingham (SB), James H. Burkhard (JHB), Suh Urk Chung (SUC), Frank S. Crawford, Jr. (FSC), Orin I. Dahl (OID), Jerome S. Danburg, (JSD), Phil Dauber (PD), Don Davies (DD), Joseph C. Doyle (JCD), Philippe Eberhard (PE), Stanley M. Flatté (SMF), Jerome H. Friedman (JHF), Eugene Gellert (EG), Lawrence K. Gershwin (LKG), Robert L. Golden (RLG), Ronald A. Grossman (RAG), David J. Herndon (DJH), Lyndon M. Hardy (LMH), Richard I. Hess (RIH), Paul L. Hoch (PLH), J. Richard Hubbard (JRH), Allen Kirschbaum (AK), Janos Kirz (JK), Fred Kreiss (FK), Lester J. Lloyd (LJL), Gerald R. Lynch (GRL), Jerry Manning (JM), Terry S. Mast (TSM), Maxine Matison (MM), Donald H. Miller (DHM), Richard Muller (RM), Joseph J. Murray (JJM), William J. Podolsky (WJP), Le Roy R. Price (LRP), Morris Pripstein (MP), Robert K. Rader (RKR), Alan Rittenberg (AR), Arthur H. Rosenfeld (AHR), Ronald R. Ross (RRR), Joseph A. Schwartz (JAS), Daniel M. Siegel (DMS), Dennis B. Smith (DBS), Gerald A. Smith (GAS), Lawrence H. Smith (LHS), Paul Soding (PS), Frank T. Solmitz (FTS), Robert J. Sprafka (RJS), M. Lynn Stevenson (MLS), Robert D. Tripp (RDT), Lambert Van Loon (LVL), Alain Verglas (AV), Michael Wahlig (MW), Victor Waluch (VW), Robert D. Watt (RDW), Bryan Webber (BW), A. Barry Wicklund (ABW), Charles G. Wohl (CGW), Wolfgang Wöischnig (WW), Stanley G. Wojcicki (SGW), Lauren Yazolino (LY).

RESEARCH WITH BUBBLE CHAMBERS

Associated Production Experiment

Between mid-1960 and mid-1961, the 72-inch hydrogen bubble chamber was exposed to π^+ and π^- beams at six laboratory-system momenta from 1.030 to 1.325 GeV/c. About 1 000 000 pictures were taken, of which three-fourths have been analyzed at Berkeley and the remainder at the University of Wisconsin and Purdue, Johns-Hopkins, and Duke Universities. Numerous results from this experiment have been published. In late 1964 an additional 10 000 pictures of π^- incident at five different momenta from 0.910 to 1.030 GeV/c were taken for analysis at Berkeley.

Hyperon Production and Decay

Study of the reaction $\pi^- p \to \Sigma^0 K^0$ at an incident pion momentum of 1.17 GeV/c has been completed.[1] Study of $\pi^- p \to \Lambda K^0$ and $\pi^- p \to \Sigma^- K^+$ at the same momentum has continued, as has study of $\pi^- p \to \Lambda K^0$ at momenta below 1.03 GeV/c (the threshold for Σ production). (JAA, FSC, JCD)

Radiative Hyperon Production (or Decay)

About 20 events of the type $\pi^- p \to \Lambda K^0 \gamma$ have been identified and are being studied. (All are double vees. The gamma ray is inferred kinematically; i. e. it does not materialize in the hydrogen.) They represent a fraction of order 1/137 of the nonradiative double vees. Whether the gamma ray arises in the production process or in a subsequent decay of a hyperon (or meson) is not known. (RAG, FSC)

Lifetimes of K_1^0 and Λ

A publication is being prepared. (RLG, FSC)

Search for $\eta \to \pi^+\pi^-\pi^0$ and $\eta \to \pi^+\pi^-\gamma\gamma$

A systematic search has been made for the decay modes $\eta \to \pi^+\pi^-\pi^0\gamma$ and $\eta \to \pi^+\pi^-\gamma\gamma$ where the etas were produced in the reaction $\pi^\pm p \to \pi^\pm p \eta$ with incident pion momenta 1170 and 1030 MeV/c. We have found no events of either type. Upper limits on these two decay modes have been determined. A publication is in preparation. (LRP, FSC)

An Analysis of $\eta \to \pi^+\pi^-\pi^0$ and the Branching Ratio $\eta \to (3\pi^0)/(\pi^+\pi^-\pi^0)$

We have completed an analysis of the $\eta \to \pi^+\pi^-\pi^0$ Dalitz plot, using a power-series expansion. In contrast to other analyses, we find that a low branching ratio $\eta \to (3\pi^0)/(\pi^+\pi^-\pi^0)$ is completely consistent with this Dalitz plot if one assumes the three pions to be in only the pure T = 1 state. A publication is in preparation. (LRP, FSC)

Radiative Pion Production

We have expanded our study of the two-prong (e. g. $\pi^\pm p \to \pi^\pm p\gamma$) and four-prong (e. g. $\pi^\pm p \to \pi^\pm p \pi^+\pi^-\gamma$) events to include the six-prong topology. We are now primarily using events in which the gamma ray has materialized in the hydrogen, although events with kinematically determined gamma rays are still being analyzed. Our analysis has also been extended to cover many more energy intervals (pion beam momentum from 900 to 1200 MeV/c). (RAG, LRP, FSC)

Production of η Mesons

A detailed study of the angular distributions and absolute cross sections for etas produced via $\pi^\pm p \to \pi^\pm p\eta$ at incident pion momenta from 900 to 1200 MeV/c is being continued. The final pion-proton system is found to have a large admixture of $N^*(1238)$. In addition a significant amount of I = 1/2 amplitude is present. (RAG, LRP, FSC)

π63 Experiment

The analysis of this experiment, totalling 30 000 events/mb in the 72-inch chamber exposed to π^- in the momentum range of 1.5 to 4.2 GeV/c, is in its final states. A number of papers have been published or submitted for publication.

Low-Mass $K\bar{K}$ Systems Produced in $\pi^- p$ Interactions Below 5 GeV/c

The $K\bar{K}$ system was studied in the momentum range 1.5 to 4.2 GeV/c.[2] The $K_1^0K_1^0$ effective mass spectrum from $\pi^- p \to nK_1^0K_1^0$ shows a significant enhancement near threshold (1060 MeV, Γ = 80 MeV) at all momenta. The most natural explanation for this enhancement in these data appears to be as a manifestation of a large scattering length in the I = 0 $K\bar{K}$ system. The well-known ϕ meson was observed in the reaction $\pi^- p \to \phi n$ below 2.3 GeV/c, decaying into K^+K^-, with production and decay distributions similar to those for $\pi^+ n(p) \to \omega^0 p(p)$. No significant enhancement was seen in the I = 1 $K\bar{K}$ channel near threshold. (RIH, OID, LMH, JK, DHM)

1. J. A. Anderson, F. S. Crawford, and J. C. Doyle, Phys. Rev. 152, 1139 (1967).

2. Phys. Rev. Letters 17, 1109 (1966).

Decay Properties of the A_2 (1320) Meson[3]

The spin and parity of the A_2 meson were determined independently from its $K\bar{K}$ and $\pi\rho$ decay modes. It was shown, that if reasonable assumptions are made concerning the background, both decay modes support the $J^P = 2^+$ assignment. (SUC, OID, LMH, RIH, JK, DHM)

Strange-Particle Production in π^-p Interactions

Three-and-more-body final states.[4] Cross sections for the constrained final states were measured as a function of beam momentum. Peripheral production of low-lying resonances was found to be the outstanding feature of the reactions. Dalitz plots and their projections were constructed for the three-body final states. Production of Y_0^* (1405), Y_0^* (1520), Y_0^* (1815), Y_1^* (1385), K^* (890), and K^* (1440) was observed as well as the $K\bar{K}$ decays of the A_2 and the ϕ meson. Cross sections and angular distributions for production and decay of these resonances were determined. Results concerning the K^* (890) were compared with absorption model predictions. Effective-mass distributions for particle pairs and triplets were given for the four-body final states. In these states the D and E mesons and simultaneous Y^*K^* production were also seen. Evidence concerning the quantum numbers of the A_2, the D, the E, and the K^*(1440) was discussed. The behavior of the $K\bar{K}$ system near threshold was examined. A small amount of Ξ production was observed, and the Ξ^* (1530) was also seen. (OID, LMH, RIH, JK, DHM)

Two-body final states.[5] The reactions $\pi^-p \rightarrow \Lambda K^0$, $\Sigma^0 K^0$, and $\Sigma^- K^+$ were studied in the 1.5- to 4.2-GeV/c momentum range in the Lawrence Radiation Laboratory's 72-inch hydrogen bubble chamber. The total cross sections for the three reactions decrease as $E_{c.m.}^{-3.6}$, $E_{c.m.}^{-3.3}$, and $E_{c.m.}^{-9.3}$ respectively. The differential cross sections were determined at 11 beam momenta. A peripheral peak is the dominant feature of the reactions $\pi^-p \rightarrow \Lambda K^0$ and $\Sigma^0 K^0$ for which K^* exchange is allowed, but no such peaking is seen in $\pi^-p \rightarrow \Sigma^- K^+$. An exponential fit to the momentum-transfer distributions in the peripheral region yields slope parameters in the 6 to 10 $(GeV/c)^{-2}$ range. The differential cross sections for $\pi^-p \rightarrow \Lambda K^0$ and $\Sigma^- K^+$ show peaking for forward-produced hyperons in the c.m., where baryon exchange is expected to contribute. The angular distribution of the Λ polarization in $\pi^-p \rightarrow \Lambda K^0$ was measured. (OID, LMH, RIH, JK, DHM, JAS)

K72 Experiment

$K^-p \rightarrow \Lambda\eta$

The reaction $K^-p \rightarrow \Lambda\eta$ where the η decays via various channels has been investigated. The results of a study of the production-angle distribution and total cross sections has been submitted to Phys. Rev.[6] Branching ratios of the η have been determined:[6,7]

$$(\eta \rightarrow \text{neutrals})/(\eta \rightarrow \pi^+\pi^-\pi^0) = 3.6 \pm 0.6;$$
$$(\eta \rightarrow \pi^+\pi^-\pi^0\gamma)/(\eta \rightarrow \pi^+\pi^-\pi^0) < 0.07.$$

(SMF, CGW)

K63 Experiment

The 72-inch bubble chamber has been exposed to 30 000 events/mb of K^- beams having laboratory momenta of 1.70, 2.10, 2.45, 2.58, 2.63, and 2.70 GeV/c. Exposures with deuterium in the chamber were taken at 2.1 and 2.7 GeV/c, and a run was made at 2.1 GeV/c with a lead plate in the chamber to convert γ rays and thus detect neutrals. The film was taken between mid-1963 and early 1965.

$K^-p \rightarrow \Lambda\omega$

The reaction $K^-p \rightarrow \Lambda^0\omega$ from 1.2 to 2.7 GeV/c was analyzed by means of the absorption model with K and K^* exchange. This analysis, with an evaluation of coupling constants and comparison with SU(3), will be published in Phys. Rev.[8] (SMF)

The Reactions $K^-p \rightarrow \bar{K}^0 n$ and $K^-p \rightarrow \pi^0\Lambda$

The process of cleaning up V 0-prong events by comparing and resolving discrepancies between two film scans and remeasuring failing events has been completed at the

3. Phys. Rev. Letters 18, 100 (1967.)
4. O. I. Dahl, L. M. Hardy, R. I. Hess, J. Kirz and D. H. Miller, Strange-Particle Production in π^-p Interactions from 1.5 to 4.2 GeV/c. Part I. Three-and-More-Body Final States, UCRL-16978, January 1967, submitted to Phys. Rev.
5. O. I. Dahl, L. M. Hardy, R. I. Hess, J. Kirz, D. H. Miller, and J. A. Schwartz, Strange-Particle Production in π^-p Interactions from 1.5 to 4.2 GeV/c. Part II. Two-Body Final States, UCRL-17217, January 1967, submitted to Phys. Rev.
6. S. M. Flatté and C. G. Wohl, The Reaction $K^-p \rightarrow \Lambda\eta$ from 1.2 to 1.7 GeV/c, UCRL-17515, April 1967; submitted to Phys. Rev.
7. S. M. Flatté Search for $\eta \rightarrow \pi^+\pi^-\pi^0$, UCRL-17514, April 1967; submitted to Phys. Rev. Letters.
8. S. M. Flatté, Can the A_1, K_c, D, and E Form a Nonet? Alvarez memo 579 (1966). To be published in Phys. Rev. 156, (1967).

momenta we are concentrating on (2.1, 2.45, and 2.7 GeV/c). This cleaning up has been necessary in order to reduce systematic effects to within the good statistical-error limits on cross-section determinations. Semifinal results give hope that we may be able to determine spins and parities of the higher Y^* resonances seen in the total cross section measurements of Cool et al.[9] (ABG, RDT, CGW)

The Reactions $K^-p \rightarrow p\bar{K}^0\pi^0\pi^-$ and $K^-p \rightarrow \bar{K}^0\pi^+\pi^-n$

A systematic study of the reactions $K^-p \rightarrow p\bar{K}^0\pi^0\pi^-$ and $K^-p \rightarrow n\bar{K}^0\pi^+\pi^-$ is in progress. Production cross sections are being measured for the well-known resonances. A detailed study of the associated production of $K^{*-}(892)$ and $N^{*+}(1238)$ is being made, including the production differential-cross-section and the multiple-decay correlations. This study compares these correlations with the predictions of exchange models with absorptive corrections.

Studies of the $K\pi\pi$ mass spectra have revealed two statistically significant enhancements at 1280 and 1410 MeV. The nature of these enhancements is under investigation. (JHF, RRR)

The Reactions $K^-p \rightarrow \Lambda\pi^+\pi^0\pi^-$ and $K^-p \rightarrow \Lambda\pi^+\pi^-$

In a continuing study of the production of the $Y^*(1385)$, ρ, and ω resonances, results have been reported on relative cross sections and production angular distributions of the quasi two-body states $Y^{*+}\rho^-$, $Y^{*0}\rho^0$, and $Y^{*-}\rho^+$, and on the masses of Y^{*+}, Y^{*0}, and Y^{*-}. Investigations of decay angular distributions of Y^* and ρ, and absolute cross sections, are in progress. A thesis based on a study of these reactions is being written by one of us. (DMS, RRR)

Production and Decay of Cascade Hyperons

Production and decay of Ξ^- and Ξ^0 are being studied systematically, using K^-p film at incident momenta of 1.7 and 2.1 to 2.7 GeV/c. The sample of about 3 200 Ξ^- and 1 200 Ξ^0 represents roughly half the world's supply of analyzed cascade events. All well-constrained reactions with up to five bodies in the final state are included; total cross sections for each reaction as a function of energy are being determined, as well as partial cross sections for resonant intermediate states. Differential cross sections and polarizations are being measured for Ξ^-K^+ and Ξ^0K^0 production, and a partial-wave analysis of Ξ^-K^+ will be performed in collaboration with the UCLA group (Data for incident K^- momenta of 1.8 to 2.0 GeV/c exists at UCLA). A study of resonance production is in progress, including a spin-parity determination of Ξ^{*0}.

An analysis of the normal $\Lambda\pi^{\overline{0}}$ decay of $\overline{\Xi^0}$ is underway, including determination of lifetime, spin, and decay-asymmetry parameters. The lifetime determination of Ξ^0 should greatly improve the precision to which this quantity is presently known thus, enabling us to check the $\Delta I = 1/2$ production $\tau\Xi^0 \approx 2\tau\Xi^-$.

A search for leptonic and $\Delta S = 2$ decay modes is also in progress. This search has already yielded two unambiguous examples of $\Xi^- \rightarrow \Lambda^0 e^- \nu$ to add to the previous world total of two sure and one or two doubtful decays of this type. No other unusual decays have been found, but the sample is not yet exhausted.

Results of the cascade analysis will be presented in a paper to be submitted to The Physical Review. Results of the partial-wave analysis of Ξ^-K^+ and of a study of the Ξ^* production mechanism will be published separately. (PD, JPB, JRH)

Study of the Reaction $K^-p \rightarrow \Sigma^{\pm}\pi^{\mp}$

An analysis of charged $\Sigma\pi$ production by K^- on protons from 2.1 to 2.7 GeV/c is in progress. Total and differential cross sections as well as Σ^+ polarization are being measured. The data will be fit to a model including S-channel production of resonances and Regge poles in the t and u channels. The model will be extended below 2.1 GeV/c using data analyzed at LRL and UCLA. (ABG, PD)

Study of the Reaction $K^-p \rightarrow \Lambda^0\pi^+\pi^+\pi^-\pi^-$

Resonance production in the $\Lambda 4\pi$ reaction is being studied with emphasis on a search for decay chains of the type $Y^* \rightarrow Y_1^*(1385)$ or $Y_0^*(1520)$ plus one or more pions. Copious production of $Y_1^*(1385)$ and $Y_0^*(1520)$ is observed and there are indications that these states are decay products of heavier Y^*'s. (PD)

K^- Interactions in Deuterium

The deuterium film of path length 5 events/μb equally divided between 2.1 and 2.64 GeV/c has been scanned. Approximately 50 000 events having (a) three or four prongs with or without a secondary decay, and (b) one-to four-prongs with a V have been measured on the Franckenstein and the Spiral Reader. Special emphasis has been placed on

9. R. L. Cool et al., Phys. Rev. Letters 16, 1228 (1966).

measuring the three- and four-prong with V events, of which three-fourths are now measured. From these events, those fitting the reaction $K^-n \to \Lambda + X^-$ (X^- is any state decaying into $\pi^+\pi^-\pi^-$ plus possible unobserved neutrals) are being studied to determine the isospin of $\eta'(958)$. Tentative results confirm our earlier I = 0 assignment. The $K^-n \to \Sigma^-\pi^+\pi^-(\pi^0)$ final states are being studied to check on the existence of I = 2 $\Sigma\pi$ resonances. Also being studied is the reaction $K^-n \to \Sigma^-X^0$, where X^0 is a meson decaying into 3π or $2\pi\gamma$. These last two studies are being carried out in collaboration with a SLAC bubble chamber group. (ABG, AR, MM)

Reactions $K^-p \to \Sigma^\pm\pi^\mp\pi^0, \Sigma^\pm\pi^\mp\pi^+\pi^-$, $K^-p\pi^+\pi^-$, $K^-p\pi^+\pi^-\pi^0$

The study of the 4-body Σ reactions above led to an unambiguous determination of the spin, parity, and width of the $Y^*(1660)$. The decay of that particle into $\Sigma\pi\pi$ has been explained with the help of a model involving the interference of the cascading resonance chain $Y^*(1660) \to \Lambda(1405) + \pi$ with other processes involving the $\Sigma(1385)$ and an isospin-one nonresonant $\Sigma\pi$ amplitude. A paper has been submitted to Phys. Rev. Letters.[10] (PE, MP)

The study of the 3-body Σ reactions is still dominated by the problem of getting more measurements in order to better the statistics and improve the analysis of resonance production. (PE, MP)

Analysis of the reactions $K^-p \to K^-p\pi^+\pi^-$ and $K^-p\pi^+\pi^-\pi^0$ is continuing with improved statistics. (MP)

LRL-SLAC

LRL-SLAC is experimenting on π^-p inelastic reactions near the $N^*(1688)$ resonances. About 100 000 events have now been measured, and data analysis is in progress. (JPB, LRP, AHR, PS)

K65 Experiment

From August 1965 to June 1966, the 25-inch hydrogen bubble chamber was exposed to a K^- beam of about 400 MeV/c. Roughly 1.2 million pictures were taken, with an average of about six kaons per picture. All film has been scanned once, yielding 450 000 events, and about 20% of the film has been rescanned. Of a total of 160 000 measured events, about 100 000 have been measured on Spiral Reader I. All events have been processed on the CDC 6600 computer, and the analysis is in progress.

Study of Σ Decay Parameters

In order to measure the decay parameters γ_+^+, γ_-^-, β_+^+, and β_-^- we have scanned and measured roughly 70% of our film for the reactions $\Sigma^\pm \to \pi^\pm + N$, $N + p \to N + p$, where the neutron subsequently scatters from a proton in the chamber. The β and γ are determined by the left-right asymmetry in the n-p scatter. We have so far about 2000 candidates for the above sequence of reactions. We hope to complete our scanning and publish the results in the near future.

Σ^- Leptonic Decays and Interactions

Negative Σ hyperons coming to rest in hydrogen interact with protons to make Λ's and Σ^0's, the Σ^0 subsequently decaying to a Λ. The form of the amplitude for the direct production of Λ is being studied, with 450 of 750 events already measured. No definite results have yet been obtained.

The rare leptonic decays of the Σ^- are being studied for correlations between the polarization of the Σ^- and the direction of the lepton. About 50 000 Σ^- decays have been analyzed, of which about 60 events are leptonic. About 40 are electrons, and 20 are muons. Cabibbo's theory of leptonic decay predicts two possible values of the correlation coefficient for these decays; preliminary analysis does not readily distinguish between these two, although one is favored. More data are needed, and we hope to be able to extend our run at the Bevatron to increase the statistics.

Σ^+ Magnetic Moment

A preliminary figure for the magnetic moment of the Σ^+ has been calculated from the first 6000 Σ's analyzed. A more statistically significant figure, to be compared with theoretical predictions from SU(3), will be calculated when the remaining Σ events have been analyzed.

Study of K^0

The K65 experiment has provided photographs of about 300 leptonic K^0 decays. A study of their distributions in time and angle is in progress, giving information on the hadron currents involved in these processes. At present there are no indications that they fail to conserve (S-Q) and CP. The time distribution of 70 three-pion decays is also being studied for signs of CP violation.

10. P. Eberhard, M. Pripstein, F. T. Shively, V. E. Kruse, and W. P. Swanson, A Determination of the Spin and Parity of the $Y_1^*(1660)$, UCRL-17590, May 26, 1967; submitted to Phys. Rev. Letters.

The Reaction $K^- p \to \Lambda + n\pi$

The $\Lambda\pi^+\pi^-$ final state is being analyzed for evidence of $Y_0^*(1520) \to Y_1^*(1386) + \pi$. This is relevant to the SU(3) classification of the $Y^*(1520)$ and the structure of the $3/2^-$ octet. Three thousand events have been measured on the Frankenstein, and a comparable number on the Spiral Reader. A remeasurement of events with unsatisfactory fits has been begun on the Frankenstein. Analysis of these events is starting with the aim of understanding the character of the nonresonant $\Lambda\pi\pi$ background.

Thirteen thousand Λ-missing-mass events have been measured on the Spiral Reader. The polarization and angular distributions of the $\Lambda\pi^0$ part of these are being analyzed. This channel is of particular interest, since it is in a pure $I = 1$ state.

Charge Exchange ($K^- p \to \bar{K}^0 n$) and Elastic ($K^- p \to K^- p$) Reactions

The momentum range of the incident K^- has been extended up to 430 MeV/c.

About 17 000 charge-exchange events have been measured with the Spiral Reader and processed through the programs SIOUX-ARROW. The production angular distribution has been analyzed in terms of Legendre polynomial coefficients (A_ℓ/A_0). An accurate measurement of the cross section ($\sim A_0$ term) will be available after the remeasurement of the failing events.

In order to solve the remaining ambiguities resulting from the study of the differential cross section alone, the polarization of the outgoing neutron must be measured. Half of the total sample has been scanned for the recoiling protons of the reaction

$$n + p \to n + p.$$

Some events have been processed in order to check the behavior of the different programs involved.

The elastic events are necessary in order to compute the amplitudes of the two isospin channels. We have measured and processed 5000 events of this type. Their analysis is progressing. (MAG, ROB, ABG, FSC, LKG, DJH, GRL, TSM, JJM, FTS, MLS, RDT, AV, BW).

P65

We are presently preparing a final report on the production of strange particles in p-p collisions at 5.5 and 6.6 GeV/c incident momentum. This is an LRL-UCLA collaboration involving approximately 12 000 events, scanned and measured jointly by the two institutions. Two papers on the subject were presented at the 1967 A. P. S. meeting in Washington.[11, 12] The main emphasis has been placed on a detailed treatment of the one-pion-exchange model, which is a good representation of the data at low momentum transfers. There is no evidence for the production of strange, di-baryon resonances in this experiment. The data in this experiment resulted from an exposure of the 72-inch hydrogen bubble chamber at the Bevatron in late 1965.

In the same bubble chamber film we have measured 40 000 four prong interactions. One of the authors (GAS) gave an invited paper at the Washington A. P. S. meeting (1967),[13] in which the results of this analysis were presented. This is an extension of work published by the LRL-UCLA collaboration.[14] Measurements were made on the Spiral Reader, with ionization information being used for the final analysis. This work emphasizes the detailed comparison of off-the-mass-shell pion-nucleon scattering with on-the-mass-shell data. One definite result is that our data strongly suggest the enhancement observed in counter experiments near 1400-MeV mass is simple a kinematic effect resulting from the one-pion-exchange at low momentum transfers. We are currently measuring approximately 30 000 two-prong interactions. This is motivated by the hope to be able to duplicate the counter-experiment results, thus demonstrating conclusively the kinematic enhancement at 1400 MeV. A final report on this work should be forthcoming in about two months. (EG, GAS, ABW, WW)

π66 Experiment

Analysis of strange-particle events produced in $\pi^+ d$ interactions in the 2.8- to 4.2-GeV/c range. A total of 21 000 events has been measured and partially processed through the data-reduction system. Attention is directed at those states containing $K\bar{K}$ pairs with and without additional pions, and those with ΛK and ΣK pairs. The nonstrange events in this experiment are being analyzed at Purdue and Illinois. (MAA, OID, JSD, PLH, JK, DHM).

11. W. Woischnig, G. A. Smith, A. B. Wicklund, S. Wojcicki, W. Dunwoodie, and H. K. Ticho, Bull. Am. Phys. Soc. Series II, 12, 505 (1967).

12. A. B. Wicklund, G. A. Smith, W. Woischnig, S. Wojcicki, W. Dunwoodie, and H. K. Ticho, Bull. Am. Phys. Soc. Series II, 12, 505 (1967).

13. Gerald A. Smith, Experimental Results on $\bar{p}$-p Collisions at Intermediate to High Energies, invited paper presented at the Spring 1967 meeting of the American Physical Society, Washington, D. C., April 24-27, 1967.

14. E. Gellert, G. A. Smith, S. Wojcicki, E. Colton, P. E. Schlein, and H. K. Ticho, Isobar Production in $p+p \to p+p+\pi^+ +\pi^-$ at 6.6 GeV/c, Phys. Rev. Letters 17, 884 (1966).

An exposure of the 72-inch deuterium-filled chamber to π^+ mesons with a variety of momenta in the range of 1.1 to 2.3 GeV/c is being analyzed. So far 32 000 events have been measured on the Spiral Reader. Primary attention is given to a study of the production of η, ω, $\eta'(960)$, and ϕ mesons as a function of the incoming beam momentum. (MAA, DD, OID, JK, DHM, RKR, GAS, JM).

D66 Experiment

We are presently engaged in an extensive study of deuteron-deuteron interactions at about 4.5 GeV/c, based on an exposure of approximately 210 000 pictures taken in the 72-inch deuterium-filled bubble chamber at the Bevatron in the spring of 1966. To get information on the effects of proton background in the beam, we also took about 20 000 pictures with the chamber exposed to a proton beam at the same momentum, 4.5 GeV/c, and about 3.500 pictures with a proton beam at one-half this momentum. A first scan and a partial second scan of all the film has been completed. In addition, a special scan to determine the d-d total cross section has recently been completed, and a result will soon be forthcoming. The events are being measured on the Spiral Reader and the measurement data then processed on the CDC 6600, using the new set of Alvarez group programs (TVGP, SQUAW, ARROW). To date, about 55 000 events have been measured (mostly three- and four-prong topologies). Results of these measurements are being analyzed and preliminary results on some d-d interactions will be forthcoming in the near future. (PE, GRL, MP).

BP66 Experiment

A 72 000 picture p-p exposure was made in the Brookhaven National Laboratory 80-inch hydrogen bubble chamber in November 1966. Incident beam momenta were 13, 18, 21, 24, and 28.5 GeV/c, with roughly equal amounts of film at each of the five momenta.

Scanning for all topologies is well underway. To date (May 1, 1967) about 40% of the film has been first-scanned and about 20% has been double-scanned. During a special part of the scan the scanners recorded all interactions as well as the number of beam tracks incident into the fiducial region. The results[15] of this special scan were cross sections for n-prong ($n \leq 14$) topologies up to 28.6 GeV/c, and (the results) were presented at the Washington APS meeting in April 1967.

About 3 000 measurements have been made on Franckenstein MPIIB and have been used to test programs. Another 500 events have been measured on Spiral Reader I -- also to debug programs. Production measurement of n-prongs ($n \leq 6$) will await completion of Spiral Reader II with the 80-cm scan. Strange-particle multiple vertex events are being measured on MPIIB.

Work will be done in several areas:

1. Survey of cross sections for simple topologies as a function of incident proton momentum.
2. Testing of the Castagnoli formula using p-p collisions.
3. A search for "fireballs" in the many-pronged events.
4. Study of the trends revealed in (1) to aid in the design of experiments for the LRL-NASA balloonproject HAPPE.

(OID, JHF, JK, DBS, LHS, RJS, MW)

$\bar{P}67$

We anticipate taking 10 000 pictures of antiprotons in hydrogen in the BNL 31-inch bubble chamber in June or July, 1967. The incident momentum will be 1.5 to 1.8 GeV/c. The purpose of the experiment is to investigate the production of nonstrange boson resonances. This may be done by analyzing interactions in the final state or, since the proton-antiproton system has baryon number zero, by a study of the direct process through cross-sectional (total and differential) dependence. (MAA, AR, GAS, RJS)

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15. R. J. Sprafka, J. A. Anderson, O. I. Dahl, J. H. Friedman, J. Kirz, M. A. Wahlig, L. H. Smith, and T. B. Day, Energy Dependence of Charged-Prong Multiplicity in p-p Interactions, UCRL-17366 Abs., February 1967.

OTHER RESEARCH PROJECTS

AEC-Supported Projects

Neutral-Diboson Spark-Chamber Experiment

In a collaboration with the Moyer-Helmholz group at LRL, we are now preparing a spark-chamber experiment at the Bevatron to study the reaction $\pi^- p \rightarrow n\pi^0\pi^0$ between 1.5 and 2.5 GeV/c. The principal purpose of the experiment is to analyze the π^0-π^0 system in a search for scalar mesons and to measure the π-π phase shifts. Other goals are to measure the branching ratios of the neutral decay modes of the $\eta(550)$ and $\omega(783)$ mesons from the reactions $\pi^- p \rightarrow n\eta(550)$ and $\pi^- p \rightarrow n\omega(783)$, respectively.

The reactions will be identified by detecting all final-state particles. The detection equipment will consist of a set of very large spark chambers to detect γ-rays, and a set of neutron counters to measure neutron time-of-flight from the liquid hydrogen target, at all polar laboratory angles from about 0 to 80 deg with respect to the incident beam direction. The spark chambers are between seven and eight radiation lengths thick and form five of the six faces of a cube with the target at the center so that the solid angle for detection of γ-rays is large.

According to the present Bevatron schedule, setting up the equipment at the accelerator will begin in October, and the experiment will then start about two to three months later. Twenty-five periods of Bevatron time have been allotted for tune-up and forty periods for data taking. In this running time we anticipate collecting about 8 000 events of the desired type to study the peripheral production of the diboson $\pi^0\pi^0$ system. (OID, MP, MW)

Deuteron Missing-Mass Experiment

Equipment is being fabricated to perform an experiment to measure the mass spectrum of particles recoiling against a deuteron produced in pp collisions at various incident proton momenta.

An enhancement in the I = 1 nonstrange boson system has been observed at 960 MeV in two different experiments.[16,17] We intend to verify the existence of this effect and to measure its excitation as a function of energy. The experiment will consist of measuring the momentum spectrum of deuterons produced in a liquid-hydrogen target placed in the external proton beam. The deuterons will be identified by their time of flight as well as the absence of veto from water Cerenkov counters. The momentum measurement will be by means of wire spark chambers placed on two sides of a bending magnet. An on-line data-acquisition system that will simultaneously record onto tape the spark coordinates, beam intensity, time of flight, and other relevant information is being constructed. (MAA, GAS, LHS)

Particle Yields and Secondary Beams at SLAC

In November and December 1966, one of the first experiments at SLAC was completed by a collaboration between LRL, SLAC, Stanford, Purdue, and the University of Hawaii. Yields were measured of $\pi^\pm$, $K^\pm$, $p^\pm$, and $e^\pm$ from several targets, at production angles of 2- and 3-deg, with secondary momenta between 4 and 14 GeV/c, from 18-GeV primary electrons. Preliminary results have been published in Phys. Rev. Letters,[18] and a more comprehensive paper is being prepared for Phys. Rev. The results of the study qualitatively confirm the predictions of the Drell mechanism[19] and ρ production, except that an excess of K^+ over K^- indicates that associated production of some kind is large, and a very large proton-antiproton ratio (~10) indicates some other mechanism is producing protons.

These measurements and those of the dynamic crossed-field electron multiplier (DCFEM) have been used to design a beam now under construction at SLAC. The beam will provide $\pi^\pm$ between 5 and 14 GeV/c, and if an rf separator is added, K^+ at 12 GeV/c, with the 82-inch bubble chamber as detector. A proposal is being prepared on behalf of most of the Alvarez group, requesting film from the 82-inch bubble chamber, since that chamber is expected to begin providing film in late 1967. (SMF, JJM, SGW)

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16. J. Oosten, P. Charanon, M. Crozon, and J. Tocquerville, Phys. Letters 22, 708 (1966).
17. W. Kienzle, B. Maglic, B. Levrat, F. Lefebvres, D. Freytag, and H. Blieden, Phys. Letters 19, 438 (1965).
18. S. M. Flatté et al., Phys. Rev. Letters 17, 366 (1967).
19. S. D. Drell, Phys. Rev. Letters 5, 278 (1960); S. D. Drell, Rev. Mod. Phys. 33, 458 (1961); J. S. Ballam, M Report No. 200, W. W. Hansen Laboratories of Physics, Stanford University, 1960 (unpublished).

Radiofrequency Detector for High-Energy Particles

The DCFEM--a microwave-gated photo multiplier tube built at LRL--has been tested, and some of its properties determined, in an experiment at the Stanford Linear Accelerator Center.

In order to study the bunch structure of a secondary beam at SLAC, the DCFEM was mounted on a Cerenkov counter which gave about seven photoelectrons per detected particle on the average, and the DCFEM was phased carefully with the linac. With the output of one DCFEM, it was determined that less than 3% of the secondary beam is contained in the half-cycle away from the linac bunch, and with two DCFEM's in coincidence, this limit was reduced to 0.01%. From data such as these it is now known that the LRL version of the DCFEM is sensitive during about one-half of the rf cycle, and that the inherent sensitivity ratio between the sensitive and the insensitive half-cycles is about four (which can be raised to an indefinite level depending on the number of Cerenkov photons per particle, the discrimination levels, and the number of DCFEM's in coincidence).

At the same time, of course, the rf bunch structure of a secondary beam at SLAC was investigated. It was shown that the rf bunch of the secondary beam has a half width of less than 10 deg of phase, and that the tail of the bunch extending over the half cycle of the phase between bunches contains less than 0.1% of the particles. This indicates that a one-stage rf-separated secondary beam will work well at SLAC. During this experiment time-of-flight differences of 0.15 nsec were measured over a flight path of 22 nsec. (SMF, JJM, SGW)

Flux Pump

A very sensitive magnetic flux amplifier is under construction. Some parts of the amplifier have been tested, and the assembly will be tested soon. (PE)

UAR/USA Pyramid Project

During the preceding six months the design and construction of a wide-angle, high-resolution, cosmic ray telescope has been completed at the Lawrence Radiation Laboratory for use in the location of unknown chambers in the Pyramids at Giza. The telescope utilizes three layers of conventional plastic scintillation counters to detect the incoming mu mesons. Two layers of wire spark chambers with magnetostrictive digital read-out are placed above the iron absorber to determine the incident angle of the particle to high accuracy, approximately 3 mrad. However, the overall precision is limited by the Coulomb scattering in the limestone. We will "harden the beam" by the addition of approximately 5 ft of iron. The overall precision will then be about 40 mrad.

We have been able to obtain commercially a wire cloth woven from 6-mil copper wire in the warp and stranded fiberglass in the woof. The cloth is then epoxyed to a fiberglass sheet and the copper wires are connected to an aluminum backing plate. This technique avoids the tedious stringing of wires in a frame and significantly reduces the cost of the spark chambers. As well as insuring good mechanical strength, the aluminum plate makes the chamber "look" more like a conventional plate chamber, in the electrical sense. A detailed analysis of the electrical properties is complicated, but the aluminum backing plate provides a number of features that are desirable for good chamber operation.

Our spark-chamber telescope was in constant operation since December, 1966 until shipment in March 1967. The overall system efficiency is slightly greater than 80%. Approximately 5% is lost by chamber double sparking, caused by electrons that have been Coulomb-scattered by mu mesons. Ten per cent is lost because of the construction geometry. (This 10% had to be sacrificed in order to make the spark chambers small enough to go down the Pyramid passageway.) The remaining five per cent is lost for miscellaneous reasons, primarily spark-chamber misfiring.

The electronics for the system was designed with reliability as the primary design criterion, and in this respect the design has been exceedingly successful. In almost three months of continuous operation at the Lawrence Radiation Laboratory, the equipment has required very minor maintenance, and we are completely convinced that the equipment will withstand the severe environment. The apparatus is now being assembled at the Pyramid Site in Cairo and will be in operation in June 1967. It is estimated that the survey of the first Pyramid will take about six months continuous operation. (LWA, JAA, SB, JHB, FK, LY)

High-Altitude Particle-Physics Experiment

In this program cosmic radiation will be used to extend the study of high-energy interactions beyond present accelerator energies. To accomplish this our apparatus will be carried to 15-mb residual altitude (93 000 ft) by a tandem mylar-scrim balloon. For our physics requirements two flights a year, each of about 20-h duration, will be made to supply us with 10 000 particles per flight. The vehicle carrying the instrumentation will land at sea and be recovered by ship.

Design is complete for a gondola that will provide a momentum-analyzed beam of protons greater than 100 GeV/c and pions greater than 14 GeV/c. Provisions have been made in the gondola for experiments that will later be made below the analyzed beam; however, no steps have been taken toward building this equipment. This gondola will accumulate 10 000 events of the above analyzed particles per 20-h flight.

The beam is analyzed in two steps: (1) the beam passes through a gas Cerenkov detector, which discriminates against the more numerous low-energy particles, and (2) the momentum is measured by a combination of spark chambers and emulsions with a magnetic field. The major items of equipment for the Cerenkov and momentum-analysis portion of the gondola have been fabricated. One Cerenkov detector has been built, and various pieces have been tested to the extent possible at sea level.

Cerenkov Detector

One Cerenkov detector was flown with a balloon from Chico, California, to test the integrity of the bag material, the gas valve's ability to compensate for changes in altitude, and the accuracy of particle-threshold control, and to measure above-threshold rates encountered at altitude. Data from this flight are now being analyzed.

Another Cerenkov detector is being assembled for a flight in July 1967. This detector will be made to provide a maximum geometry factor and utilize anticoincidence scintillators around each of the 5-in. Cerenkov photomultipliers. The anticoincidence scintillators were found necessary from the balloon flight made July 1966 of a 1/3-scale model of the counter system. It was noted on this flight that many below-threshold particles were causing pseudo-Cerenkov pulses by going through the photomultiplier tube. Data from the flight made in February 1967 will be used to evaluate the effectiveness of these anticoincidence detectors in eliminating false Cerenkov pulses.

The Cerenkov detector now under assembly has its photomultiplier tubes and mirror housed in an aluminum cone along with the scintillators below the gas bag. This "cone" has been fabricated and the elements (antiscintillators, mirrors, and photomultiplier supplies) are being installed. A photomultiplier supply is potted in Silastic on the base of each tube, thus eliminating the need to distribute high voltage in the reduced atmosphere at higher altitudes. Extensive testing on these phototube supplies has shown that they regulate to 2% between 20 and -30°C.

Extensive magnetic shielding is required around all photomultiplier tubes in the gondola because of the large stray field. The absence of iron in the superconducting magnet compounds the stray-field problems. A phototube shield utilizing both silicon iron and μ-metal has been tested under fields expected during the flight.

Momentum Analysis

The momentum-analysis portion of the gondola is divided into three sections - the spark chambers, the emulsions, and the magnet. These are contained in the spool and Dewar sections of the gondola. The superconducting magnet, which is the most critical section of the momentum-analysis portion, is presently being wound at the Lawrence Radiation Laboratory in Livermore. Completion of the superconducting magnet is now scheduled for August 1967.

Recent tests of a new titanium alloy superconductor have shown that the magnet can be run at fields up to 15 kG with this wire. The decision was made to use the new wire, and all of this new superconductor has been delivered and is now being wound on the magnet. Changes in the mechanical structure of the magnet and the use of this new superconductor will allow us to increase the operating field to 13 kG, 25% higher than expected six months ago. Future structural changes are necessary to utilize the full 15-kG capability.

The first of two spark chambers necessary for the momentum-analysis section of the Gondola is now being assembled and will be flown in the engineering flight scheduled for July 1967. These spark chambers were designed for minimum maintenance after filling with neon because of the possible long delay between the time of installation and of flight on the gondola. They will be able to run for long periods with no gas flushing while maintaining high sparking efficiency. The most essential characteristic of the spark-chamber systems, however, is that they locate and record to ±200μ the location of the particle's trajectory. To accomplish this, great care has been taken to insure that the optical system for the spark chamber introduces little distortion. The mirrors were constructed by laminating two sheets of flat glass on either side of stainless steel honeycomb, thus making them light in weight and structurally stiff.

The engineering flight, HAPPEF-1 (High Altitude Particle Physics Experimental

Facility will fly one emulsion on the emulsion-supporting structure. Temperature transducers will be placed on the titanium-beryllium frame to determine what temperature insulation and control will be necessary to maintain dimensional stability between the emulsions. The engineering data accumulated on a 1/3-scale model indicate that the dimensions can be controlled to enable momentum of a 100-GeV/c proton to be measured to 2.5% and that of a 1 000-GeV/c proton to 20%.

Small sample emulsions have been poured on both sides of Herculite glass to determine the effect of the emulsion on the chemically tempered glass. After several trials this technique was perfected; further work now in progress is developing pouring techniques for large-sized emulsions that will not introduce distortions.

Scanning

The scanning machine for these large emulsions (1-in-diam) has been built, and laser interferometers have been installed for coordinate measurement. Engineering specifications on the machine indicate that x-y positional accuracy of $1/3\mu$ is possible. A PDP-8 computer was purchased to link the laser-interferometer output to the drive motors and scanning controls. This scanning machine is tightly linked to the overall problem of "trackfinding," that is, correlating a spark-chamber track to a particular emulsion. This has been accomplished by the spark-chamber emulsion arrangement flown July 1966 (HAPPE-0). Tracks were located in two nuclear emulsion stacks, one in the laboratory and another flown to 15 mb. Only 80% success was achieved on the events made at high altitude, due to the large electron background. A further test is now ensuing to develop better recording accuracy to cope with the high electron background.

Operations

The immediate focus of our efforts lies on the summer balloon flight of HAPPEF-1. A contract has been let to the G. T. Schjeldahl Company for the balloon operations. They will build the balloon and launch the system using a "Stonehenge" launch method. Because of this relatively new method of launching a heavy payload, a successful test of the launch was made in April.

The balloon will be tracked during flight, and the gondola will be located at sea by a Loran repeater system and telemetry. Two complete telemetry stations have been built for this purpose and were tested on the Cerenkov-detector flight in February. One station is mobile and will be located down frange from the launch. The other will be located aboard a ship. Extensive investigations are in progress to determine the best deployment of in-sea tracking and locating equipment.

Within the next few months a survey of the additional sites will be made for possible launching areas. Hawaii is ideally situated for launching, since a sea recovery is possible all year around (Chico, for example, is limited to summer flights because the winter high-altitude winds are predominantly from the west). The more southern latitudes are also optimum from the standpoint of particle backgrounds. The higher geomagnetic cutoff of Hawaii (11 GeV/c), for example, would eliminate ten times more background than Chico (geomagnetic cutoff of 3 GeV/c).

At this date the following flights are planned or have been executed:

HAPPE-0,	1/3-scale detector system with spark-chamber emulsion track-finding, July 1966;
HAPPE-1/2,	full-scale Cerenkov detector, February 1967;
HAPPE-3/4,	launch test of a full sized mock-gondola, April 1967;
HAPPEF-1,	full-scale gondola and counter system, less the superconducting magnet, July 1967;
HAPPEF-2,	HAPPEF-1 system with the magnet to make a "beam survey," early 1968.

Future Endeavor

The first flight of the full-scale system remains foremost in our efforts, even while executing the test of the vehicle on HAPPEF-1. Many systems not needed on this engineering flight will be needed for HAPPEF-2, such as the data-analysis system and the momentum-analysis assembly. More development will be needed for a reliable track-finding technique, and measurement of the emulsion system will be investigated extensively. The logistical problems will be surveyed to allow us to make flights more economically and at more desirable locations.

Upon receipt of the superconducting magnet in August, we will integrate in it an emulsion—spark—chamber system to find tracks in the emulsion with the magnet running. This test will serve to bring out any problems associated with running the spark chambers and electronics under high ambient magnetic fields. (LWA, JAA, PD, AK, LJL, RM, DBS, LHS, MW, LVL, VW).

BUBBLE CHAMBER OPERATION AND DEVELOPMENT

Robert D. Watt in charge

25-Inch Hydrogen Bubble Chamber

At the start of the report period, the chamber was operating in the University of Wisconsin (Fry-Camerini) K^- deuterium run. The chamber operated in the double-pulse mode every other pulse because of beam compatability problems with other experiments.

In December, the deuterium was dumped and the chamber filled with hydrogen to continue the Murray K65 experiment. The experiment was terminated on December 19 because of Bevatron generator failure.

A total of 99 rolls of film (1.7×10^5 pictures) were taken for the two groups.

Personnel from the 25-in. crew have since been assisting on the conversion of the 72-in. chamber to 82 in.

72-Inch Hydrogen Bubble Chamber

The chamber was in operation with hydrogen during the report period for the Trilling-Goldhaber and Powell-Birge groups. A total of 424 rolls of film (2.97×10^5 pictures) were taken.

The 72-in. chamber terminated operation as a vapor-expansion-type chamber on December 9, 1966 after 7-3/4 years of operation as a physics research tool. Over 11×10^6 feet of film have been processed. This represents approximately 8.2×10^6 stereo triplets.

72- to 82-Inch Chamber Conversion

Since Building 59 is being demolished ahead of the original schedule, the cold engineering run of the completed system will be conducted at SLAC. A warm test of the expansion system will be done at LRL. The 72-in. magnet was moved to the Bevatron Annex, where assembly of the 82-in. chamber is progressing.

Because the contractor has failed to deliver a hydro-formed bellows, a bellows simiiar to the 25-in. -chamber bellows has been fabricated at LRL and welded in the chamber.

The hydrogen shield has been assembled to the top plate, and a myriad of plumbing attached thereto. The large glass window has been polished, and fiducials have been applied and measured. The new vacuum tank is installed in place. The drive rods and hydraulics system are being assembled at the present time.

The completed chamber and magnet will be moved to SLAC in midsummer.

DATA REDUCTION OPERATIONS

Personnel

The group was authorized to boost its effort level from 73 to 88 full-time equivalents (FTE). The assembled effort figures for this period are:

Month	Gross effort (FTE)	Net effort (FTE)
November	89.5	78.3
December	84.6	74.6
January	83.4	75.5
February	81.9	62.7
March	76.5	70.2
April	94.5	89.5
Average	85.1	75.1

The figures under the gross-effort column represent the total effort assigned to the Scanning and Measuring payroll account. To arrive at the net-effort figures, deduct sick leave, vacation, holidays, and leave without pay from the gross effort. The net effort, then, is the effort available for group use. In comparison with the preceding semiannual period, we have realized (on the average) a gain of 5.7 FTE, or a 7.3% increase in the gross effort.

Scanning

APE

The total scanning and measuring effort devoted to the APE experiment for this period was 6749 h. This represents 14.2% of the group's total effort. In this effort 360 rolls of film were scanned with the following breakdown:

Event Types

First scan	Rolls
Two-prongs	10
Three-, four-, and six-prongs, and single-vee events (π^- film)	274
Three-, four-, and six-prongs, and single-vee events (π^+ film)	21
Subtotal	305

Second scan	Rolls
Three-, four-, and six-prongs, and single-vee events (π^- film)	50
Three-, four-, and six-prongs, and single-vee events (π^+ film)	5
Subtotal	55
APE total	360

P65

The total scanning and measuring effort devoted to P65 was 6641 h, 14.0% of the group total. The experiment consists internally of two separate experiments: Experiment 17 (pp at 6.6 GeV/c), and Experiment 24 (pD_2 at 6.6 GeV/c). The scanning done was mostly devoted to special scans (twice-failing events, ambiguities, etc.) with the total scanning amounting to 493 rolls.

Event Types		Rolls
First scan		
Experiment 17:	Two-prongs	50
Experiment 24:	Nonstrange-particle events	7
	Subtotal	57
Special scans		
Experiment 17:	Resolution of twice-failing or ambiguous strange-particle events	307
Experiment 24:	Resolution of twice-failing or ambiguous nonstrange-particle events.	129
	Subtotal	436
	P65 total	493

PI66

With a total scanning-and-measuring effort of 12 329 h during the period (25.9% of the group effort), PI66 was able to scan 898 rolls between its three constituent experiments. Experiment 18 (π^+D_2 at 2.8 to 4.2 GeV/c) accounted for 423 rolls, Experiment 25 (π^+D_2 at 1.1 to 2.3 GeV/c and pD_2 at 2.1 GeV/c) added another 457 rolls, while Experiment 26 (pp at 13 to 28 GeV/c) accounted for the remaining 108 rolls. The breakdown is as follows:

Event types		Rolls
First scan		
Experiment 18:	All vee'd events	19
Experiment 25:	Three-, four-, five-, and six-prongs; all vee'd events; one- and two-prongs with obvious protons	317
Experiment 26:	All topologies	30
	All topologies except two-prongs	16
	Subtotal	382
Second scan		
Experiment 18:	All vee'd events	43
Experiment 25:	Three-, four-, five-, and six-prongs; all vee'd events; one- and two-prongs with obvious protons	10
	All vee'd events	30
Experiment 26:	All topologies	10
	All topologies except two-prongs	12
	Subtotal	105
Experiment 18:	Cross section	35
	Ambiguities	276
	Conflicts	50
Experiment 25:	Cross section	90
	Conflicts	10
Experiment 26:	Cross section	40
	Subtotal	411
	PI66 total	989

K65

K65 received 9817 h of scanning and measuring effort during this period, 20.7% of the group effort. A great deal of K65 scanning time was devoted to recoil scans in preparation for the Washington Conference in April. The 910 rolls scanned were divided as follows:

Event types	Rolls
First scan	
Strange-particle events	95
Second scan	
Strange-particle events	120
Special scans	
Recoil events	600
Conflict	95
Subtotal	695
K65 total	910

K63

Over the period the average scanning and measuring effort was 25.2% of the group effort, giving a total of 12012 h devoted to the experiment. As can be seen from the breakdown, Experiment 23 (pD_2 and D^+D_2 at 4.5 GeV/c) accounted for 323 rolls, the most significant portion of K63's scanning effort. Lesser amounts were devoted to Experiment 12 (K^-p at 1.7 to 2.7 GeV/c), and Experiment 14 (K^-D_2 at 1.7 to 2.7 GeV/c), with their totals being 1540 and 300 rolls respectively.

Event types

First scan	Rolls
Experiment 23: Three- and four-prongs	35
All except one- and two-prongs	245
Subtotal	280

Second scan	
Experiment 12: Tau decays	140
Experiment 23: All except one- and two-prongs	40
Subtotal	180

Event types

Special scans	
Experiment 12: Ambiguous events	1400
Experiment 14: Ambiguous events	300
Experiment 23: Cross section	3
Subtotal	1703
K63 total	2163

Measuring

The number of events measured during this period showed an increase of 84429 events, or approximately 29.2% over the previous period. The greatest share of the increase was borne by the Spiral Reader, which measured at unprecedented rate during this period.

Machine	Events	Measuring hours
IIA	26251	2791
IIB	18729	2596
IIC	28725	2955
IID	24474	3354
All Franckensteins	98179	11696
Spiral Reader I	274581 [20]	3381
Total	372760	15014

As Spiral Reader II gradually becomes operational during the next six months, our measuring output should increase rapidly, reaching an instantaneous rate of more than 10^6 events per year by the end of Calendar 1967.

20. The vertex-oriented nature of the Spiral Reader dictates the necessity of the addition of one further statistic: during this period the Spiral Reader measured 361055 vertices.

DATA-REDUCTION DEVELOPMENT

Lester J. Lloyd, Norman R. Andersen, Glenn T. Armstrong,
James N. Baldridge, Roy Carlson, Alice T. Lee,
Gerald Lynch, and Frank Solmitz

Spiral Reader Development and Operation

During the past six months Spiral Reader I has measured nearly 300 000 events from six different experiments. The reliability and speed of the machine have improved to the extent that measurements are being made about 80% of the time, and as many as 3000 events have been measured in one day. A three-reel film drive system has been built and tested for this machine and will be used soon. In the next few months this machine will be moved from its present location in Building 46 to Building 50B.

Spiral Reader II has been built and tested and moved from Building 46 to Building 50B. All systems are now operational except for the automatic fiducial system and the laser crutch-point system. Spiral Reader II is expected to start production this month.

Spiral Reader Programming

Many improvements have been made to the Spiral Reader filter program POOH to reduce the failure rate of the program. Most of this effort was directed toward making the program work well for new experiments.

New calibration programs have been developed that make calibration of the Spiral Reader faster and more accurate, although this increased accuracy has yet to be incorporated into POOH.

The PDP-4 program has been modified to operate Spiral Reader II and to operate the three-reel film drive. Work continues on a new improved general program.

PROGRAMMING EFFORT

The computer programs described in this report involved the programming efforts of the following persons:

Robert J. Harvey

(Supervisor of the Alvarez Programming Group)

G. T. Armstrong	B. J. Cottrell	W. O. Koellner
J. N. Baldridge	O. I. Dahl	M. Leavitt
J. P. Berge	C. T. Draper	A. J. Lee
G. M. Brandon	N. L. Gould	E. A. Romascan
J. H. Burkhard	M. S. Hutchinson	J. D. Stedman
R. E. Carlson	D. L. Iverson	T. R. Tonisson
R. W. Casey	N. K. Joseph	J. J. Wilson

Introduction

At the time of the last progress summary, most Alvarez Programs had already been converted to the CDC 6600. For the past six months, much of the effort has been directed toward developing these programs to take maximum advantage of the new system. New programs have been developed in conjunction with the Pyramid and Balloon Projects. Major programs have continued to be maintained and changes made in support of the physics research program.

General Information

Alvarez Group programs may be divided roughly into the following six general classifications:

1. Data-Editing Programs: designed to prepare (i.e. select, order, sort, etc.) data from various measuring devices for processing through the physics programs.
2. Data-Analysis Programs: designed to analyze (e.g. reconstruct, fit, plot, etc.) data for purposes of extracting its scientific content.
3. Library-Function Programs: designed to serialize, manipulate, and keep track of data for reference purposes.
4. Support Programs: routines which perform miscellaneous functions in support of the programs in the above categories.
5. Spiral Reader Programs: codes associated with the control, operation, and support of the Spiral Reader. (See also Alvarez Data Reduction Development.)
6. Cosmic Ray Programs: programs associated with the Balloon and Pyramid Projects.

The following annotations summarize the work of the Alvarez Group Programming Staff in each of the above areas for the period November through April 1967:

Data-Editing Programs

PANAL. This program orders and sorts events via experiment, roll, frame, and beam track. Modifications were made to the 7044/94 PANAL versions. The CDC 6600 version of PANAL is being completed.

MATCH. This CDC 6600 program which does three-view track correlating is being revised. It now includes event- and experiment-dependent data read from the disc, and a MATCH-ordered Panal-formated output tape.

Data-Analysis Programs

SOUCI. This is the 6600 combined three-view geometry and kinematic-fitting program. An addition is being made, whereby a different set of track parameters are used to define stopping, neutral, and two-point charged non-stopping tracks. An arithmetical-error restart procedure has been developed, and the I/0 has been changed to include double buffering (see P-164).

ARROW. This CDC 6600 program for processing SOUCI output has been speeded up and the core size has been reduced.

CSUMX. A chain version of the CDC 6600 ASUMX, the CSUMX program has all of the features of ASUMX, but takes less core space (see P-163).

Library-Function Programs

LYRIC III. The net operating time of this CDC 6600 version of the main library program has been reduced, and the standard Alvarez Group I/0 routines are now being used. Special conflict routines for experiment K65 have been added. The following routines have been added or changed:

a. LYCARD, the scan-card translating program, now properly handles beam-track scans for all experiments.

b. CORECT changes information on PANAL or data-summary formated tapes. It may be used alone or in conjunction with LYRIC III.

LYRIC II. This is the 7044/94 version of the main library program. HYDRA, the LYRIC II I/0 routine, has been modified to allow reading of multi-reel tape files.

MESH. This 7044 program allows the merging of a Panal event with a recoil associated with that event.

SORT. This is a CDC 6600 ordering program for various types of output tapes (see P-161). Additions have been made that allow stacking of any number of input tapes and separating by experiment number the ordered output tapes.

Support Programs

POHIST. Written for the CDC 6600, this new summary program makes statistical calculations on data in conjunction with the POOH program. POHIST does histogramming, averaging, and makes RMS calculations for each roll, operator and tape.

PHHIST. This CDC 6600 program makes histograms of pulse-height information from POOH output tapes.

STEEP. This CDC 6600 Spiral Reader optical-calibration program has been speeded up and reduced in size.

CHANT. This program punches Franckenstein control cards from special format scan cards.

PATHOS/LG. Each calculates $d\sigma/d\Omega$ and polarization for the reaction $K^-p \rightarrow \Sigma^\pm \pi^\mp$ by using different methods. PATHOS calculates the coefficient of Legendre polynomials, and LG calculates Regge poles plus resonances.

Spiral Reader Programs

POOH. This combined track-filtering and track-correlating CDC 6600 program for Spiral Reader data is being revised so that it can handle data from Spiral Reader II and can use the new system of optical-mechanical calibration constants generated by the Program STEEP.

Cosmic Ray Programs

(HAPPEF) This stands for High Altitude Particle Physics Experimental Facility, commonly known as the Balloon project. The following are programs associated with this project:

a. LOON is a program being written for the PDP-8 to shuffle pulse-height and count-rate information.

b. BALNOPT is a CDC 6600 spark-chamber optical-calibration program under development.

c. ELEBCK/MUBCK. These two CDC 6600 programs calculate the number of high-energy electrons and muons at various altitudes resulting from proton interaction.

PYRIM. This program was written for the Pyramid Project. It is a Monte Carlo routine simulating the cosmic ray pyramid data. The program is operational on the CDC 6600 and IBM 7044.

GHBHST/GHBRHST. These set up a library system for the IBM 7044 to be used during processing of actual Pyramid data. They are operational on the 6600 and 7044.

Programming Notes

The following programming notes have been written during the last six months:

P-153	M. S. Hutchinson	10/31/66	Alvarez Group 6600 Tape Dump (AGDMP)
P-154	O. I. Dahl D. Davies	11/18/66	CREE - SUMX Physics Tapes for PI66
P-155	M. Leavitt	11/29/66	EXTERN - A 6600 Fortran Program to Produce a Subrouting Logic Map from a FORTRAN Source File
P-156	J. Friedman	11/20/66	MURTLEBERT - A General Program for Fitting Data by the Method of Maximum Likelihood
P-157	D. L. Iverson	12/14/66	Emulsion Microscope Stage Position Print Routine for the PDP-4
P-158	J. Friedman	1/9/67	DISPLAY - A Data Display Program for the CDC 6600
P-158.1	J. Friedman	6/67	SUPER DISPLAY - Cal Comp/CRT/ Vista Console
P-159	J. Friedman D. Casey	2/7/67	MURTLEBERT for the IBM 7044/7094
P-160	J. S. Danburg G. R. Lynch	2/14/67	BUBBLE - A Program to Utilize Spiral Reader Measurements of Track Brightness
P-161	B. Cottrell	2/22/67	6600 SORT - An Ordering Routine for Master List, PANAL, SIOUX, ARROW, and SUMX Output Tapes
P-162	G. R. Lynch	3/8/67	6600 OWL - A Monte Carlo Phase-Space Program
P-163	M. Leavitt	3/20/67	CHAIN SUMX - Preliminary User Information
P-164	N. L. Gould J. J. Wilson	4/11/67	How to run SOUCI

UCRL-8030

This effort in data compilation and summary continues to expand. The January 1967 Rev. Mod. Phys. article was 50 pages long, vs. 28 pages in October 1965. It contained a new section, compilations of mass spectra, which will be continued as a regular activity. The wallet sheets were completely updated, and a sample is attached.

Working with Dr. John Hornbostel of BNL, we have inaugurated a second new activity, compilations of cross sections. We have started to collect data and write programs. The first edition will appear in about one year.

UCRL-8030 and the wallet sets are now printed and distributed simultaneously by CERN and LRL. (AHR, ABG, WJP, LRP, PS, CGW)

Data on Particles and Resonant States: Table S, Stable Particles. Rev. Mod. Phys., January 1967

A. H. Rosenfeld, A. Barbaro-Galtieri, W. J. Podolsky, L. R. Price, Matts Roos, Paul Soding, W. J. Willis, C. G. Wohl

Particle	$I^G(J^P)C_n$	Mass (MeV)	Mass difference (MeV)	Mean life (sec) $c\tau$ (cm)	Mass^2 (GeV)^2	Decays: Partial mode	Fraction	Q (MeV)	p or p_{max} (MeV/c)
γ	$0,1(1^-)^-$	0		stable	0	stable			
ν_e / ν_μ	$J=\frac{1}{2}$	0(<0.2 keV) / 0(<2.1 MeV)		stable	0	stable			
$e^\mp$	$J=\frac{1}{2}$	0.511006 ±.000002		stable ($>2\times10^{21}$ y)	0.000	stable	$\mu_e = 1.001159622 \pm .000000027\ \frac{e\hbar}{2m_ec}$		
$\mu^\mp$	$J=\frac{1}{2}$	105.659 ±.002		2.199×10^{-6} ±.001, S=1.3*; $c\tau=6.592\times10^4$	0.011	$e\nu\bar{\nu}$	100 %	105	53
	$\mu_\mu = 1.001164 \pm .000003\ \frac{e\hbar}{2m_\mu c}$					$e\gamma\gamma$	(< 1.6)10^{-5}	105	53
			-33.920 ±.014			3e	(< 1.3)10^{-7}	104	53
						$e\gamma$	(< 6)10^{-9}	105	53
$\pi^\pm$	$1^-(0^-)^+$	139.579 ±.014		2.608×10^{-8} ±.015, S=3.5*; $c\tau$ = 782; $(\tau^+-\tau^-)/\bar{\tau}$ = (.4±.2)% (test of CPT)	0.019	$\mu\nu$	100 %	34	30
						$e\nu$	(1.24±0.03)10^{-4}	139	70
			4.6041 ±.0037			$\mu\nu\gamma$	(1.24±0.25)10^{-4}	34	30
						$\pi^0 e\nu$	(1.01±0.09)10^{-8}	4	5
						$e\nu\gamma$	(3.0 ±0.5)10^{-8}	139	70
π^0	$1^-(0^-)^+$	134.975 ±.014		b 0.89×10^{-16} ±.18, S=1.6*; $c\tau = 2.67\times10^{-6}$	0.018	$\gamma\gamma$	c(98.8)%	135	67
						γe^+e^-	c(1.169)%	134	67
						$\gamma\gamma\gamma$	(< 5)10^{-6}	135	67
						$e^+e^-e^+e^-$	c(3.47)10^{-5}	133	67
$K^\pm$	$\frac{1}{2}(0^-)$	493.82 ±.11		1.235×10^{-8} ±.006, S=2.4*; $c\tau$ = 3 70; $(\tau^+-\tau^-)/\bar{\tau}$ = (.09±.08)% (test of CPT)	0.244	$\mu\nu$	b(63.4 ±0.5)% S=1.5*	388	236
						$\pi\pi^0$	(21.0 ±0.3)% S=1.5*	219	205
						$\pi\pi^-\pi^+$	(5.6 ±0.1)% S=1.5*	75	126
						$\pi\pi^0\pi^0$	(1.71±0.08)%, S=1.5*	84	133
						$\mu\pi^0\nu$	(3.41±0.22)%, S=1.9*	253	215
						$e\pi^0\nu$	(4.79±0.18)%, S=2.1*	358	229
						$\pi\pi^\mp e^\pm\nu$	(3.8 ±0.8)10^{-5}	214	204
			-4.05 ±.12			$\pi\pi^\pm e^\mp\nu$	(< 2)10^{-6}	214	204
						$\pi\pi^\mp\mu^\pm\nu$	(≤ 1.4)10^{-5}	109	151
						$\pi\pi^\pm\mu^\mp\nu$	(< 3)10^{-6}	109	151
						$e\nu$	(1.9 ±1.2)10^{-5}	493	247
						$\pi\pi^0\gamma$	(2.2 ±0.7)10^{-4}	219	205
						$\pi\pi^+\pi^-\gamma$	(10 ±4)10^{-5}	75	126
						πe^+e^-	(< 1.1)10^{-6}	353	227
						$\pi\mu^+\mu^-$	(< 3)10^{-6}	143	172
K^0	$\frac{1}{2}(0^-)$	497.87 ±0.16		50% K_{Short}, 50% K_{Long}					
K_{Short}	$\frac{1}{2}(0^-)$			0.87×10^{-10} ±.009, S=1.3*; $c\tau$ = 2.61	0.248	$\pi^+\pi^-$	(69.3 ±1.2)% S=1.25*	219	206
			$-0.48\times\frac{1}{\tau_S}$ ±.02			$\pi^0\pi^0$	(30.7 ±1.2)%	228	209
K_{Long}	$\frac{1}{2}(0^-)$			5.68×10^{-8} ±.26; $c\tau$ = 1703	0.248	$\pi^0\pi^0\pi^0$	(23.5 ±2.1)%	93	139
						$\pi^+\pi^-\pi^0$	(11.5 ± .4)%	84	133
						$\pi\mu\nu$	(27.5 ±1.8)%	253	216
						$\pi e\nu$	(37.4 ±1.8)%	358	229
						$\pi^+\pi^-$	(.153 ±.007)%	219	206
						$\pi^+\pi^-\gamma$	(< 0.3)%	219	206
						$\pi^0\pi^0$	(< 2.7)10^{-3}	228	209
						$e\mu$	(< 4)10^{-5}	392	238
						$\gamma\gamma$	(1.3 ±0.6)10^{-4}	498	249
						$\mu^+\mu^-$	(< 4)10^{-6}	287	225
						e^+e^-	(< 4)10^{-5}	497	249
η	$0^+(0^-)^+$	548.6 ±0.4		1<Γ<10 keV; $(2<c\tau<20)10^{-9}$		Neutral decays 72.9%: $\gamma\gamma$	(31.4 ±2.2)%	549	274
						$\pi^0\gamma\gamma$	(20.5 ±3.5)% S=1.3*	414	258
						$3\pi^0$	(21.0 ±3.2)% S=1.5*	144	179
						Charged decays 27.1%: $\pi^+\pi^-\pi^0$	(22.4 ±1.8)%	135	174
						$\pi^+\pi^-\gamma$	(4.6 ±0.8)% S=1.1*	269	236
						$\pi^0e^+e^-$	(< 0.2)%	413	258
						$\pi^+\pi^-e^+e^-$	(0.1 ±0.1)%	268	236

Particle	$I^G(J^P)C_n$	Mass (MeV)	Mass difference (MeV)	Mean life (sec) $c\tau$ (cm)	Mass^2 (GeV)^2	Partial mode	Fraction	Q (MeV)	p or p_{max} (MeV/c)	Magnetic moment ($e\hbar/2m_pc$)	Measured α	Measured Φ(degree)	Derived γ	Derived Δ(degree)
p	$\frac{1}{2}(\frac{1}{2}^+)$	938.256 ±0.005		stable ($>6\times10^{27}$ y)	0.880					2.792763 ±.000030				
			-1.2933 ±.0001											
n	$\frac{1}{2}(\frac{1}{2}^+)$	939.550 ±0.005		$(1.01\pm.03)10^{+3}$; $c\tau = 3.03\times10^{13}$	0.882	$pe^-\nu$	100 %	1	1	-1.913148 ±.000066				
Λ	$0(\frac{1}{2}^+)$	1115.58 ±0.10		2.51×10^{-10} ±.04, S=1.4*; $c\tau$ = 7.52	1.245	$p\pi^-$	(66.4 ±1.1)% S=1.1*	38	100	-0.73 ±.16	.663±.022	(-7±7)°	.74	(8±8)°
						$n\pi^0$	(33.6 ±1.1)%	41	104		.73 ±.18	Sign of φ and Δ changed after RPM printing to correct for wrong sign in listed data card.		
						$pe\nu$	(0.88±0.15)10^{-3}	177	163		.06 ±.19			
						$p\mu\nu$	(1.35±0.60)10^{-4}	72	131					
Σ^+	$1(\frac{1}{2}^+)$	1189.47 ±0.08		0.810×10^{-10} ±.013; $c\tau$ = 2.43	1.412	$p\pi^0$	(52.8 ±1.5)%	116	189	2.3 ±.6	-.960±.067	(180±30)°	-1.0	(0±85)°
						$n\pi^+$	(47.2 ±1.5)%	110	185		+.008±.037			
						$p\gamma$	(1.9 ±0.4)10^{-3}	251	225					
						$n\pi^+\gamma$	(≈ 0.2)10^{-4}	110	185					
						$\Lambda e^+\nu$	(1.5 ±0.9)10^{-5}	73	72					
						$n\mu^+\nu$	(< 1.1)10^{-4}	144	202					
			-7.97 ±.11			$ne^+\nu$	(< 5)10^{-5}	249	224					
Σ^0	$1(\frac{1}{2}^+)$	1192.56 ±0.11		$<1.0\times10^{-14}$; $c\tau<3\times10^{-4}$	1.422	$\Lambda\gamma$	100 %	77	75					
			-4.88 ±.06			Λe^+e^-	c(5.45)10^{-3}							
Σ^-	$1(\frac{1}{2}^+)$	1197.44 ±0.09		1.65×10^{-10} ±.03, S=1.4*; $c\tau$ = 4.95	1.434	$n\pi^-$	100 %	118	193		-.010±.043			
						$ne^-\nu$	(1.25±0.17)10^{-3}	257	230					
						$n\mu^-\nu$	(0.62±0.12)10^{-3}	152	210					
						$\Lambda e^-\nu$	(0.61±0.16)10^{-4}	81	79					
						$n\pi^-\gamma$	(≈ 1)10^{-5}	118	193					
Ξ^0	$\frac{1}{2}(\frac{1}{2}^+)$?	1314.7 ±1.0		3.0×10^{-10} ±.5, S=1.3*; $c\tau$ = 8.99	1.728	$\Lambda\pi^0$	100 %	64	135		-.33 ±.10			
						$p\pi^-$	(< .5)%	237	299					
						$pe^-\nu$	(< .6)%	376	323					
						$\Sigma^+e^-\nu$	(< .7)%	125	119					
			-6.5 ±.2			$\Sigma^-e^+\nu$	(< .6)%	117	112					
						$\Sigma^+\mu^-\nu$	(< .7)%	20	64					
						$\Sigma^-\mu^+\nu$	(< .6)%	12	49					
						$p\mu^-\nu$	(< .6)%	271	309					
Ξ^-	$\frac{1}{2}(\frac{1}{2}^+)$?	1321.2 ±0.2		1.74×10^{-10} ±.05; $c\tau$ = 5.22	1.746	$\Lambda\pi^-$	100 %	66	139		-.391±.032	(6±8)°	.92	(14±15)°
						$\Lambda e^-\nu$	(2.5 ±1.8)10^{-3}	205	190					
						$n\pi^-$	(< 5)10^{-3}	242	303					
						$\Lambda\mu^-\nu$	(< 1.2)%	100	163					
						$\Sigma^0e^-\nu$	(< 0.3)%	128	122					
						$\Sigma^0\mu^-\nu$	(< 0.5)%	23	70					
						$ne^-\nu$	(< 1)%	381	327					
Ω^-	$0(3/2^+)$? ?	1674 ±3		1.5×10^{-10} ±.5, $c\tau$ = 4.5	2.802	$\Xi\pi$	(~50)%	221	296					
						$\Lambda\bar{K}$	(~50)%	66	216					

Decay Parameters†

†The definition of these quantities is as follows

$$\alpha = \frac{2\,\mathrm{Re}(S^*P)}{|S|^2+|P|^2};\quad \beta = \frac{2\,\mathrm{Im}(S^*P)}{|S|^2+|P|^2};\quad \gamma = \frac{|S|^2-|P|^2}{|S|^2+|P|^2}$$

$$\tan\Phi = \frac{\beta}{\gamma},\quad \tan\Delta = \frac{-\beta}{\alpha}.$$

General Atomic and Nuclear Constants[a]

- N = 6.02252×10^{23} mole^{-1} (based on A_{C12} = 12)
- c = 2.997925×10^{10} cm sec^{-1}
- e = 4.80298×10^{-10} esu = 1.60210×10^{-19} coulomb
- 1 MeV = 1.60210×10^{-6} erg
- ħ = 6.5819×10^{-22} MeV sec
  = 1.05449×10^{-27} erg sec
- ħc = 1.9732×10^{-11} MeV cm = 197.32 MeV fermi
- k = 8.6171×10^{-11} MeV deg^{-1} (Boltzmann const.)
- α = $e^2/\hbar c$ = 1/137.0388
- m_e = 0.511006 MeV/c^2 = 1/1836.10 m_p
- m_p = 938.256 MeV/c^2 = 1836.10 m_e = 6.721 $m_{\pi^\pm}$
  = 1.00727663 m_1 (where m_1 = 1 amu = $\frac{1}{12}$ m_{C12} = 931.478 MeV/c^2)
- r_e = e^2/m_ec^2 = 2.81777 fermi (1 fermi = 10^{-13} cm)
- $\lambda\!\!\!^{-}_e$ = $\hbar/m_ec$ = $r_e\,\alpha^{-1}$ = 3.86144×10^{-11} cm
- a_∞ Bohr = $\hbar^2/m_ee^2$ = $r_e\,\alpha^{-2}$ = 0.529167 Å (1 Å = 10^{-8} cm)
- $\sigma_{Thompson}$ = $\frac{8}{3}\pi r_e^2$ = 0.66516×10^{-24} cm^2 = 0.66516 barn
- R_∞ = $m_ee^4/2\hbar^2$ = $m_ec^2\alpha^2/2$ = 13.60535 eV (Rydberg)
- Hydrogen-like atom (non-rel., μ = reduced mass) $E_n = \frac{\mu z^2e^4}{2(n\hbar)^2}$; $a_{n=1} = \frac{\hbar^2}{\mu z e^2}$; $\left(\frac{v}{c}\right)_{rms} = \frac{ze^2}{n\hbar c}$
- μ_{Bohr} = $e\hbar/2m_ec$ = 0.578817×10^{-14} MeV gauss^{-1}
- μ_{nucl} = $e\hbar/2m_pc$ = 3.1524×10^{-18} MeV gauss^{-1}
- $\frac{1}{2}\omega_{cyclotron}$ = $e/2m_ec$ = 8.79404×10^6 rad sec^{-1} gauss^{-1}; = $e/2m_pc$ = 4.7895×10^3 rad sec^{-1} gauss^{-1}.
- $\sigma_{natural}$ = $\pi(\hbar/m_{\pi^\pm}c)^2$ = 62.768 mb

Other Physical Constants

- 1 year = 3.1536×10^7 sec (≈ $\pi\times10^7$ sec)
- density of air = 1.205 mg cm^{-3} (at 20°C)
- acceleration by gravity = 980.67 cm sec^{-2}
- gravitational constant = 6.670×10^{-8} cm^{3}g^{-1} sec^{-2}
- 1 calorie = 4.184 joules
- 1 atmosphere = 1033.2 g cm^{-2}
- 1 eV per particle = 11604.9°K (from E = kT)

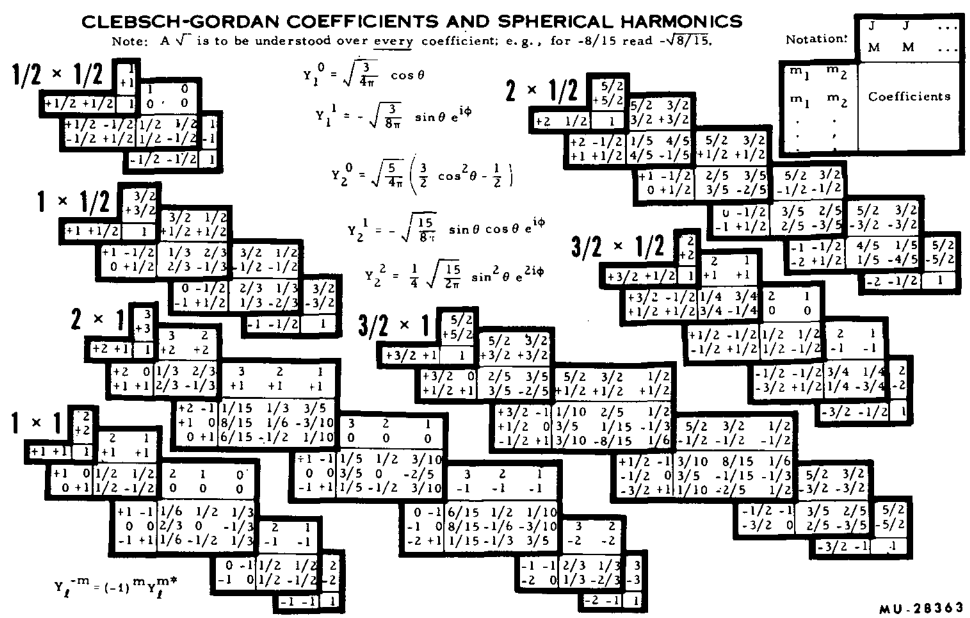
Numerical Constants

1 rad	= 57.29578 deg	e	= 2.71828
C	= 0.577216	1/e	= 0.367879
ln 2	= 0.69315	$\log_{10}e$	= 0.43429
ln 10	= 2.30259	$\log_{10}2$	= 0.30103

[a] Based mainly on E. R. Cohen and J. W. M. DuMond, Rev. Mod. Phys. 37, 537 (1965).

* S = Scale factor = $\sqrt{\chi^2/(N-1)}$ where N ≈ number of experiments. S should be ≈ 1. If S > 1, we have enlarged the error of the mean, δx, i.e., δx→S δx. This new convention, is still inadequate, since if S > 1, the real uncertainty is probably even greater than Sδx. See text.
a. See notes on Stable Particles in text. b. See notes in data card listings. c. Theoretical value. See also data card listings.
‡ In decays with more than two bodies, p_{max} is the maximum momentum that any particle can have.

MUB-13977



Atomic and Nuclear Properties of Materials

Material	Z	A	Cross Section σ^a barns	Collision Length L_{coll}^b g cm^{-2}	cm	Minimum $-dE/dx^c$ MeV g^{-1} cm^2	MeV cm^{-1}	Radiation Length L_{rad}^d g cm^{-2}	cm	Density ρ g cm^{-3}
H_2	1	1.01	0.063	26.5	374	4.13	0.292	58.0	819	0.0708[e]
D_2	1	2.01	0.100	33.4	202	2.07	0.342	116	703	0.165[e]
He	2	4.00	0.16	42.0	336	1.94	0.242	85.4	683	0.125[e]
Li	3	6.94	0.23	50.4	94.3	1.69	0.902	78.7	148	0.534
Be	4	9.01	0.28	55.0	29.9	1.60	2.96	63.7	34.7	1.848
C	6	12.01	0.33	60.4	f	1.78	f	42.4	f	≈1.55[f]
N_2	7	14.01	0.36	63.6	78.9	1.81	1.46	37.8	46.7	0.808[e]
Al	13	26.98	0.57	79.2	29.3	1.62	4.37	24.0	8.9	2.70
Fe	26	55.85	0.92	101.2	12.8	1.48	11.6	13.9	1.8	7.87
Cu	29	63.54	1.00	105.4	11.8	1.44	12.9	12.0	1.34	8.96
Sn	50	118.69	1.55	129.7	17.8	1.28	9.4	8.89	1.22	7.31
W	74	183.85	2.02	150.8	7.80	1.17	22.6	6.89	0.36	19.3
Pb	82	207.19	2.20	156.2	13.8	1.13	12.8	6.52	0.58	11.35
U	92	238.03	2.42	163.6	≈8.63	1.09	≈20.6	6.13	≈0.32	≈18.95
Air				64.6	53620	1.81	0.0022	36.5	30290	0.001205[g]
Freon (CF_3Br)				87.1	≈58.0	1.52	≈2.3	16.6	≈11	≈1.5
H_2 (bubble chamber, 27°K)				26.5	442	4.13	0.248	58.0	970	≈0.060[h]
H_2O				57.2	57.2	2.03	2.03	35.7	35.7	1.00
Ilford Emulsion				103.0	27.0		5.49	11.2	2.91	3.815
LiF				63.8	24.2	1.69	4.46	39.0	14.8	2.64
Mylar ($C_5H_4O_2$)				59.1	42.8	1.91	2.64	39.6	28.7	1.38
NaI				119.0	32.4	1.32	4.84	9.58	2.61	3.67
Polyethylene (CH_2)				51.0	≈55.5	2.09	≈1.92	44.1	≈48	≈0.92
Polystyrene (CH)				54.9	≈52.3	2.03	≈2.14	43.4	≈41.3	≈1.05
Propane (C_3H_8, bubble chamber)				48.9	119.3	2.28	0.935	44.6	109	0.41

a. $\sigma = \sigma_{natural} = \pi(\hbar/m_\pi c)^2 \times A^{2/3} = 62.8 \text{ mb} \times A^{2/3}$

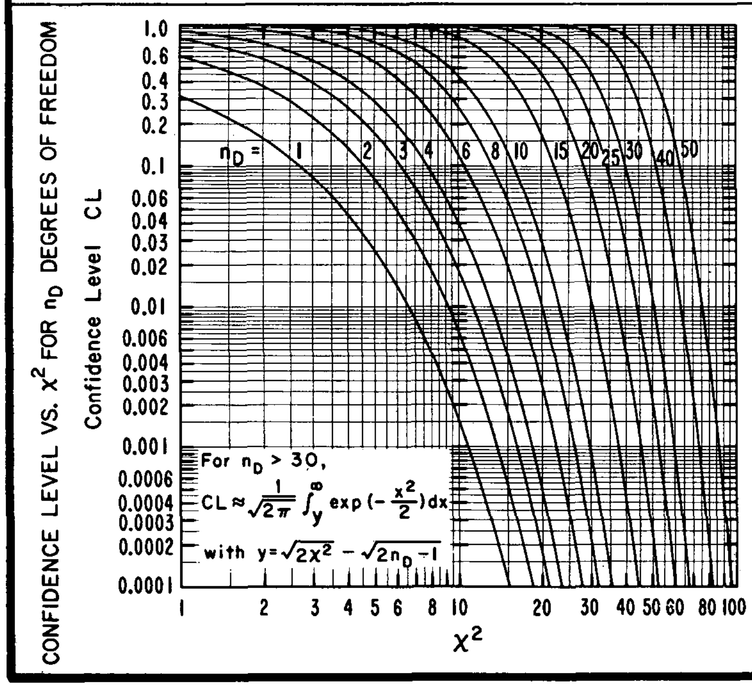
b. $L_{coll} = A/(N\sigma_{natural}) = 26.5 \text{ g cm}^{-2} \times A^{1/3}$

c. From W. H. Barkas and M. J. Berger, Tables of Energy Losses and Ranges of Heavy Charged Particles, NASA SP-3013 (1964)

d. Mainly from High Energy and Nuclear Physics Data Handbook, W. Galbraith and W. S. C. Williams, Ed. (N.I.R.N.S., Rutherford Lab., Chilton, Didcot, Berks.) 1964

e. boiling at 1 atmosphere f. density variable g. at 20°C

h. May vary by about ± 3%, depending on operation conditions



STIRLING'S APPROXIMATION

$$\sqrt{2\pi n}\left(\frac{n}{e}\right)^n < n! < \sqrt{2\pi n}\left(\frac{n}{e}\right)^n \left(1 + \frac{1}{12n-1}\right)$$

Gaussianlike Distributions

For n > -1 but not necessarily integral:

$$\int_0^\infty x^{2n+1} \exp\left[-\frac{x^2}{2\sigma^2}\right] dx = 2^n n! \, \sigma^{2n+2}; \quad \left(\tfrac{1}{2}\right)! = \sqrt{\pi}/2$$

Relation between standard deviation σ and mean deviation α:

$2\sigma^2 = \pi\alpha^2$; σ = 1.4826 probable error.

Odds against exceeding one standard deviation = 2.15:1; two, 21:1; three, 370:1; four, 16,000:1; five, 1,700,000:1

MULTIPLE COULOMB SCATTERING

The rms projected angle θ due to multiple Coulomb scattering (only) of a particle of charge z, momentum P, velocity V is

$$\theta_{proj} = z\, \frac{15(\text{MeV})}{PV(\text{MeV})} \sqrt{\frac{L}{L_{(rad)}}}\,(1+\epsilon) \text{ radians;}$$

L = Length in scatterer
For L ⩾ 1/10 L(rad) ϵ is generally < 1/10. The distribution of θ is not truly Gaussian. The rms projected displacement y on traversing an absorber of thickness L is

$$y_{rms} = L\theta_{proj}/\sqrt{3}$$

RADIOACTIVITY

1 curie = 3.7×10^{10} disintegrations/sec

1 R = 87.8 ergs/g air = 5.49×10^7 MeV/g air

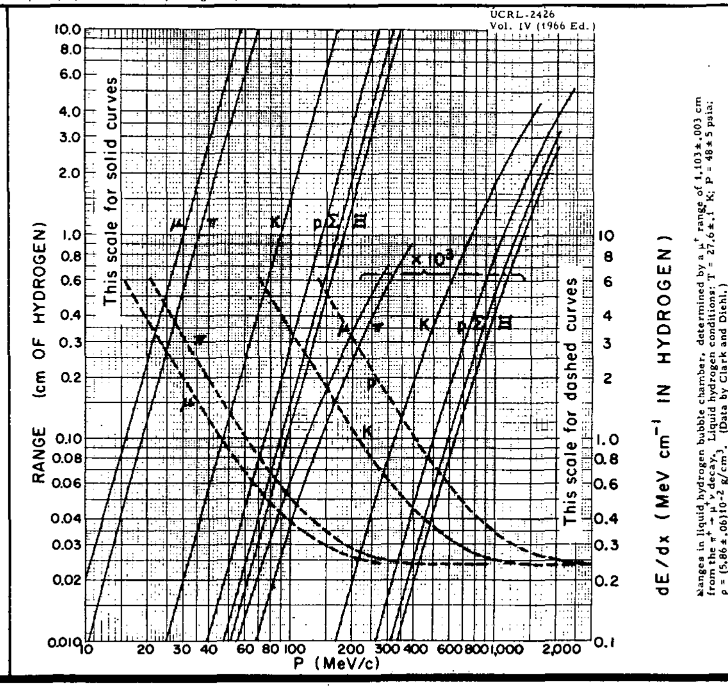
Fluxes (per cm^2) to liberate 1 R in carbon:

3×10^7 minimum ionizing singly charged particles
0.9×10^9 photons of 1 MeV energy.

(These fluxes are actually correct to within a factor of two for all materials.)

Natural background: 100 mR/year

"Tolerance" 100 millirem/week [Note, 1 R may produce up to 10 "Rem" (R equivalent for man), depending on type of radiation.]



UCRL-17544

MESONS, January 1967

Symbol(J^P)	$I^G(J^P)C_n$ (underline = estab.)	Mass M (MeV)	Width Γ (MeV)	M^2 ±ΓM[(a)] (GeV)²	Partial Decay Modes: Mode	Fraction (%)	Q (MeV)	p or p_{max}[(b)] (MeV/c)	Nonets
η(549)	$\eta(0^-)$	$0^+(0^-)+$	548.6 ±0.4	<0.01	0.301 <.000005	all neutral	73	See Table S	η
						$\pi^+\pi^-\pi^0+\pi^+\pi^-\gamma$	27		
σ, ε §									
ω(783)	$\phi'(1^-)$	$0^-(1^-)-$	783.4 ±0.7 S=1.8*	11.9 ±1.5	0.614 ±.009	$\pi^+\pi^-\pi^0$	≈ 90	369	328 (ω)
						$\pi^+\pi^-$	seen (c)	504	366
						$\pi^0\gamma$	9.7±0.8	648	380
						η + neutral	< 1.5	234	199
						$\pi^+\pi^-\gamma$	< 5	504	366
						e^+e^-	0.012±.003	782	392
						$\mu^+\mu^-$	< 0.10	572	377
η'(958) or X^0	$\eta'(0^-)$	$0^+(0^-)+$	958.3 ±0.8	<4	0.918 <.004	ηππ	75 ± 3 S=1.8*	131	232 (η')
						$\pi^+\pi^-\gamma$ (incl. $\rho^0\gamma$)	25 ± 3	679	458
						for upper limits see footnote (f)			
H§									
φ(1019)	$\phi(1^-)$	$0^-(1^-)-$	1018.6 ±0.5	4.0 ±1.0 S=1.2*	1.039 ±.004	K^+K^-	48 ± 3	31	125 (φ)
						K_LK_S	40 ± 3	23	107
						$\pi^+\pi^-\pi^0$ (incl. ρπ)	12 ± 4	604	461
						for upper limits see footnote (g)			
η_V(1050) → K_SK_S	$\eta(0^+)$	$0^+(0^+)+$	1050	50	1.10 ±.05	ππ	< 70	780	507 (η_V)
Some data still favor large scattering length						$K\bar{K}$	> 30	54	167
f(1250)	$\eta'(2^+)$	$0^+(2^+)+$	1254 ±12	117 ±15	1.57 ±.15	ππ	large	975	611 (f)
						$2\pi^+2\pi^-$	< 4	696	547
						$K\bar{K}$	2.3±0.6	258	381
D(1285)	η'(A)	$0^+(1^+)+$	1285 ±4	32 ±8	1.65 ±.04	$K\bar{K}\pi$ (mainly $\pi_V(1003)\pi$) only mode seen		154	304 (D)
						$K^*\bar{K}+\bar{K}^*K$		-100	
						ππρ	not seen	256	356
E(1420)	η(A)	$0^+(0^-)+$	1424 ±7	76 ±9	2.03 ±.11	$K^*\bar{K}+\bar{K}^*K$	50 ±10	38	157 (? / E?)
						$\pi_V(1003)\pi$	50 ±10	284	338
						ππρ	not seen	395	462
K_sK_s§, ρρ									
f'(1500)	$\eta(2^+)$	$0^+(2^+)+$	1514 ±16	86 ±23	2.29 ±.13	ππ	< 14	1235	744 (f')
						$K\bar{K}$	> 60	518	570
						$K^*\bar{K}+\bar{K}^*K$	< 40	128	294
						ηη	not seen	417	522
$\pi^\pm$(140) π^0(135)	$\pi(0^-)$	$1^-(0^-)+$	139.58 134.98		0.019 0.018	See Table S			π
$\rho^\pm$(760)	$\rho(1^-)$	$1^+(1^-)-$	778 (h)	160 (h)	0.605 ±.124	ππ	≈100	480	353 (ρ)
						$\pi^\pm\pi^+\pi^-\pi^0$	< 0.2	206	243
						$\pi^+\pi^-\pi^+\pi^-$	< 0.6	199	238
						$\pi^0\gamma$	< 0.4	619	367
ρ^0(760)			770 (h)	140 (h)	0.593 ±.108	$\eta\pi^\pm$	< 0.8	71	135
						e^+e^-	.0065 +.011 −.005	759	380
						$\mu^+\mu^-$	.0033 +.0016 −.0007	549	365
δ(965)	?( )	1( )	963.1 ±4.2	<5	0.927 <.005	$\delta^\pm$ → 1 charged+neutral(s)	≈ 60		
						$\delta^\pm$ → ≥3 charged+neutral(s)	≈ 40		
π_V(1003) → $K\bar{K}$	$\pi(0^+)$	$1^-(0^+)+$	1003	70 ±15	1.006 ±.057	$K^\pm K^0$	large	11	75 (π_V)
may also be interpreted as due to large scattering length						ηπ	see note in data listings	315	333
A1(1080)	$\pi(1^+)$	$1^-(1^+)+$	1079 ±8	130 ±40	1.16 ±.14	ρπ	≈100	181	245 (A_1)
unresolved mixture of resonance and "Deck effect"						$K\bar{K}$	< 0.25, $G=(-1)^{l+I}$ forbids this (Eq. 5)		
						ηπ	< 1.5	391	385
						η'π	< 1.5	-19	
B(1210)	ρ(A) ?	$1^+(1^+)-$??	1208 ±12	119 ±24 S=1.6*	1.46 ±.14	ωπ	≈100	297	339
						ππ	< 30	941	594
						$K\bar{K}$	< 2	232	358
						4π	< 50	662	528
						φπ	< 1.5	66	137
A2(1300)	$\pi(2^+)$	$1^-(2^+)+$ (d)	1306 ±8 S=2.6*	81 ±8 S=1.4*	1.70 ±.11	ρπ	91 ±8	408	417 (A_2)
						$K\bar{K}$	3.8±1.3	314	425
						ηπ	5 ±8 S=2.9*	618	527
						η'π	< 1.5	208	276
						$\pi^+\pi^-\pi^0$ (excl. ρπ)	< 17	892	616
π(1640) → 3π	π(A) ?	≥1^-(A)+ ?	1640 ±20	100 ±20	2.69 ±.16	3π	appears dominant	1235	792
						ρπ	< 40	746	636
						fπ	?	251	319
						$K\bar{K}$	< 40	644	652
ρ(1650) g→2π	ρ(V)	1^+(V) - S=1.4*	1637 ±23	150 ±50	2.68 ±.24	2π	observed	1358	807
$R_1R_2R_3$ bumps suggest more structure in this peak						4π	probably observed	1079	758
						ρππ	probably observed	599	605
$R_1R_2R_3$§									
S(1930) X^-	?(V) ? (e)	≥ 1^+( ) ?	1929 ±14	≤35	3.72 ≤.07	1 charged + neutral(s)	6(+15/-6)		
						3 charged + neutral(s)	92(+ 8/-20)		
						>3 charged + neutral(s)	2(+13/-2)		
T(2200) X^-	?( )	≥ 1	2195 ±15	≤13	4.82 ≤.03	1 charged + neutral(s)	4(+11/-4)		
						3 charged + neutral(s)	94(+ 6/-19)		
						>3 charged + neutral(s)	2(+13/-2)		
U(2380) X^-	?( )	≥ 1	2382 ±24	≤30	5.67 ≤.07	1 charged + neutral(s)	30 ±10		
						3 charged + neutral(s)	45 ±15		
						>3 charged + neutral(s)	25 ±10		
K^+(494) K^0(498)	$K(0^-)$	$1/2(0^-)$	493.78 497.7		0.244 0.248	See Table S			K
K^*(890)	$K(1^-)$	$1/2(1^-)$	892.4 ±0.8	49.8 ±1.7 S=1.1*	0.796 ±.044	Kπ	≈100	259	288 (K^*)
κ(725)§	$m_0-m_\pm$ = 3.5±1.8 S=1.2*					Kππ	< 0.2	119	216
K_V(1080)§ K_c(1215)§									
K_A(1320)	K(A) ?	1/2 (A) ?	1320 ±10	80 ± 20	1.742 ±.106	$K^*\pi$ (overlap)	large	288	338 (K_A)
m and Γ values taken from Shen+. Appreciable discrepancies with other experiments. See note in data listings.						Kρ (overlap)	large	63	198
						Kω	probably seen, < 10	39	155
						Kπ	< 30	687	558
						Kη	< 10	278	405
K_V(1420)	$K(2^+)$	$1/2(2^+)$	1411 ±5 S=1.8*	92 ±7 S=1.2*	1.991 ±.130	Kπ	52 ± 5	778	610 (K_V)
						$K^*\pi$	36 ± 6	379	407
						Kρ	9 ± 5 S=2.2*!	158	319
						Kω	1.0±1.7	134	293
						Kη	2.1±3.0	368	475
K_A(1800)	K (A)	1/2 (A)	1789 ±10	80 ±20	3.20 ±.14	Kπ	< 10	1156	819 (tentative)
						$K^*\pi$	35 ±12	762	664
						$K_V(1420)\pi$	8 ± 5	243	315
						Kρ	7 ± 5	532	630
						Remaining Kππ	40 ±15	1021	801
						Kω	10 ± 3	508	616
$K^*_{3/2}$(1175)§									
$K^*_?$(1270)§									

Nonets:

	CP=−1 (0^-)	CP=+1 (0^+)	CP=+1 (1^-)	CP=+1 (1^+)	CP=+1 (2^+)
Members	η, η', ?, π, K	η_V, π_V, tentative	ω, φ, ρ, K^*	D, E?, A_1, K_A, tentative	f, f', A_2, K_V
$m_8 = \sqrt{K^2 + \frac{K^2-\pi^2}{3}}$ =	566.8 ±0.2		928.4 (i)±3.0	1391. ±13.	1444.3 ±6.9
$\sin^2\theta = \frac{\eta^2 - m_8^2}{\eta^2 - \eta'^2}$ =	0.033 ±0.001		0.414 (i)±0.013	0.25 ±0.10	0.29 ±0.06
θ =	10.4°		40.1°	29.7°	32.4°

§ The following bumps, excluded above, are listed among the data cards: σ (410), ε (700), H (975), K_sK_s (1440) and ρρ (1410), R_1, R_2, R_3 (≈1700), κ (725) K_V(1080), K_c(1215), $K^*_{3/2}$(1175), $K^*_?$(1270).

* Quoted error includes scale factor $S = \sqrt{\chi^2/(N-1)}$. See footnote to Table S.

Footnotes continued in right margin.

(a) ΓM is the half-width of the resonance when plotted against M^2.

(b) For decay modes into ≥ 3 particles p_{max} is the maximum momentum that any of the particles in the final state can have. The momenta have been calculated using the averaged central mass values, without taking into account the widths of the resonances.

(c) Reported values range between 1% and 10%, and depend on assumptions on ρ-ω interference.

(d) If A2 → both ρπ and $K\bar{K}$, then $J^P = 2^+$.

(e) S is ρ(V) if identified with $\pi^+\pi^-$ bump at 1910 MeV. See note on mesons.

(f) Empirical limits on fractions for other decay modes of η'(958): $\pi^+\pi^-$ < 7%, 3π < 7%, 4π < 1%, 6π < 1%, $\pi^+\pi^-e^+e^-$ < 0.6%, $\pi^0e^+e^-$ < 1.3%, ηe^+e^- < 1.1%, $\pi^0\rho^0$ < 4%, $\pi^0\omega$ < 8%.

(g) Empirical limits on fractions for other decay modes of φ(1019): $\pi^+\pi^-$ < 20%, ηγ < 8%, η + neutrals < 13%, $\pi^+\pi^-\gamma$ < 4%, e^+e^- < 0.2%, $\mu^+\mu^-$ < 0.5%, ωγ < 5%, ργ < 2%.

(h) m_ρ, Γ_ρ from p-wave fit to compiled spectrum of 2-4 GeV/c $\pi^+p \to \Delta^{++}\rho^0$, $|t| < 10\ m_\pi^2$, and comparison of $\rho^\pm - \rho^0$ in similar reactions. Results depend on background and t-cut, hence real errors unknown, but larger than statistical errors ~ 5 MeV. (See Matts Roos, Phys. Letters, to be publ.) Note contrast between Roos' p-wave fit vs. weighted average of published results (see listings): m(±) 778 vs. 757; m(0) 770 vs. 760, Γ(±) 160 vs. 132, Γ(0) 140 vs. 116. This demonstrates present uncertainty.

(i) Error on m_ρ taken to be 10 MeV.

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BARYONS - January 1967

Class	Particle or resonance	I(J^P) (⟼ = estab.)	Beam π, K (BeV) (BeV/c)	Mass (MeV)	Γ (MeV)	$M^2 \pm \Gamma M$ (BeV²)	Mode	Fraction (%)	Q (MeV)	p or p_{max}‡ (MeV/c)	$4\pi\lambda^2$ (mb)
$N^*_{1/2}$	p n	1/2(1/2+)		938.3 939.6		0.880 0.883	See Table S				
	N'(1400)	1/2(1/2+) P_{11}	T=0.43πp p=0.55	~1400[a]	~200	1.96 ±0.28	Nπ	70	322	367	36.3
	N(1525)	1/2(3/2−) D_{13}	T=0.62 p=0.75	1525[a]	105	2.33 ±0.16	Nπ Nππ [Δ(1236)π][e]	65 35 [~ 20]	447 308 149	460 414 229	23.2
	N(1570)	1/2(1/2−) S_{11}	T=0.69 p=0.82	1570[a]	130	2.46 ±0.20	Nπ Nη	~ 30 ~ 70	492 82	491 242	20.3
	N(1670)	1/2(5/2−) D_{15}	T=0.87 p=1.00	1670[a]	140	2.79 ±0.23	Nπ Nππ [Δ(1236)π][e] ΛK Nη	40 dominant[a] [?] small small	592 453 294 57 182	560 526 357 200 368	15.6
	N(1688)	1/2(5/2+) F_{15}	T=0.90 p=1.03	1688[a]	110	2.85 ±0.19	Nπ Nππ [Δ(1236)π][e] ΛK Nη	65 dominant[a] [?] small small	610 471 312 75 200	572 538 372 231 388	14.9
	N'(1700)[c]	1/2(1/2−) S_{11}	T=0.92 p=1.05	1700[a]	240	2.89 ±0.41	Nπ	100	622	580	14.5
	N(2190)	1/2(7/2−)	T=1.94 p=2.07	2190	200	4.80 ±0.44	Nπ ΛK	30 ?	1112 577	888 710	6.21
	N(2650)	1/2(11/2−)[b]	T=3.12 p=3.26	2650 ± 10	~300	7.02 ±0.80	Nπ ΛK	7 ?	1572 1037	1154 1022	3.67
	N(3030)[c]	1/2(15/2−)[b]	T=4.26 p=4.40	3030	400	9.18 ±1.21	Nπ	0.7	1972	1377	2.62
$N^*_{3/2}$	Δ(1236)	3/2(3/2+) P_{33}	T=0.195 p=0.304	(++) 1236.0 ±0.6	120 ±2	1.53 ±0.15	Nπ Nπ⁺π⁻	100 0	158 18	231 89	91.9
		$m_0 - m_{++} = 0.45 \pm 0.85$		$m_- - m_{++} = 7.9 \pm 6.8$							
	Δ(1670)	3/2(1/2−) S_{31}	T=0.87 p=1.00	1670[a]	~180	2.79 ±0.30	Nπ Nππ	40 ?	592 453	560 526	15.6
	Δ(1920)	3/2(7/2+)	T=1.35 p=1.48	1920	200	3.69 ±0.38	Nπ ΣK	50 seen	842 229	722 423	9.37
	Δ(2420)	3/2(11/2+)[b]	T=2.51 p=2.65	2423 ±10	~275	5.87 ±0.67	Nπ ΣK	10 ?	1345 732	1024 830	4.66
	Δ(2850)	3/2(15/2+)[b]	T=3.71 p=3.85	2850 ±12	~300	8.12 ±0.86	Nπ	3	1772	1266	3.05
	Δ(3230)[c]	3/2(19/2+)[b]	T=4.94 p=5.08	3230	440	10.4 ±1.4	Nπ	0.6	2152	1475	2.24
Z^*_0	Z_0(1865)[c]	0(?)	p=1.15 K⁺p	1863	150	3.47 ±0.28	NK	55 (if J = 1/2)	432	579	14.6
Y^*_0	Λ	0(1/2+)		1115.6		1.24	See Table S				
	Λ(1405)[d]	0(1/2−)	p<0 K⁻p	1405	35	1.97 ±0.05	Σπ	100	68	142	
	Λ(1520)	0(3/2−)	p=0.392	1518.8 ±1.5	16 ±2	2.31 ±0.02	NK̄ Σπ Λππ	S=1.7* → 39±5 51±6 10±2	81 182 124	235 258 251	83.6
	Λ(1670)[a]	0(1/2−)	p=0.74	1670	18	2.79 ±0.03	Λη NK̄	K⁻p→Λη seen	6 233	66 410	28.5
	Λ(1700)	0(3/2−)	p=0.80	1700 ±10	40 ±10	2.89 ±0.07	NK̄ Σπ	20 seen	263 363	438 411	25.0
	Λ(1820)	0(5/2+)	p=1.06	1819.5 ±3.5	83 ± 8	3.31 ±0.15	NK̄ Σπ Σ(1385)π Λη	70 11 18 ~ 1	382 482 295 155	541 502 362 349	16.5
	Λ(2100)	0(7/2−)	p=1.68	2100	160	4.41 ±0.34	NK̄ Σπ	29 seen	663 763	748 699	8.68
	Λ(2340)	0(?)	p=2.27	2340 ±20	105	5.48 ±0.25	NK̄ seen in σ(total)	10 ↳ if J = 9/2	903	907	5.92
Y^*_1	Σ	1(1/2+)		(+)1189.5 (0)1192.6 (−)1197.4		1.41 1.42 1.43	See Table S				
	Σ(1385)	1(3/2+)	p<0 K⁻p	(+)1382.2±0.9 S=1.6* S=4.8* ← (−)1388.0±3.0	(+)37±3 S=2.1* (−)38±8, S=3.7*	1.92 ±0.05	Λπ Σπ	91±3 9±3 S=1.4*	130 48	208 117	
	Σ(1660)[a]	1(3/2−)	p=0.72	1660	50	2.76 ±0.08	Λ(1405)π Σπ Λπ NK̄	large ? ? small	115 323 405 223	197 379 439 400	29.9
		Large contradictions among measured branching ratios.									
	Σ(1770)	1(5/2−)	p=0.95	1768 ±4 S=1.5*	89 ±12 S=2.0*	3.13 ±0.16	NK̄ Λπ Λ(1520)π Σ(1385)π Ση Σπ	49 17 19 12 2 < 1	331 517 110 243 27 431	498 520 192 318 143 463	19.4
	Σ(1910)[c]	1(5/2+)	p=1.25	1910 ±10	60	3.65 ±0.11	NK̄ Λπ Σπ	8 10 3	473 655 573	612 619 568	12.9
	Σ(2035)	1(7/2+)	p=1.53	2035 ±15	160	4.14 ±0.33	NK̄ Λπ Σπ	16 25 seen	598 784 698	703 703 655	9.83
	Σ(2260)[c]	1(?)	p=2.06	2260 ±20	180	5.11 ±0.41	NK̄ seen in σ(total)	14 ↳ if J = 9/2	823	855	6.66
$\Xi^*_{1/2}$	Ξ	1/2(1/2+)		(0)1314.7 (−)1321.2		1.73 1.75	See Table S				
	Ξ(1530)	1/2(3/2+) p-wave		(0)1528.9±1.1 (−)1533.8±1.9	7.3 ±1.7	2.34 ±0.01	Ξπ	100	69	145	
	Ξ(1815)	1/2(?)		1815 ±3	16 ±8 S=2.2*	3.29 ±0.03	ΛK̄ Ξπ Ξππ [Ξ(1530)π][e] ΣK̄	~ 65 ~ 10 ~ 25 [~ 20] < 3	202 354 215 145	391 409 351 229	
		Branching ratios poorly known									
	Ξ(1930)	1/2(?)		1933 ±16	140 ±35	3.74 ±0.27	Ξπ ΛK̄	seen seen	472 320	501 504	
Ω^-	Ω^-	0(3/2+)		1674		2.80	See Table S				

a. See note in data listings.

b. J^P assignment based on straight-line Regge-trajectory-recurrence hypothesis and supported by fits to πp elastic scattering at 180°. See note following data listings.

c. Evidence for the existence of the effect and/or for its interpretation as a resonance is open to some question.

d. A virtual bound state of the K̄N system with negative scattering length $[a_0 = (-1.6 + 0.6i)F]$; i.e., a pole in the S matrix below the elastic threshold. See notes in main text and data listings.

e. Square brackets indicate a sub-reaction of the previous unbracketed decay mode.

† → at left of Table indicates a candidate that has been omitted because the evidence for the existence of the effect and/or for its interpretation as a resonance is open to considerable question. See listings for information on the following: $N_?(3245)$, N(3695), $N^*_{5/2}(1560)$, $Z^*_1(1910)$, Σ(1780), Σ(3000), Ξ(1705), and $\Xi_?(2270)$.

* Quoted error includes an S (scale) factor. See footnote to Table S.

‡ For decay modes into ≥3 particles p_{max} is the maximum momentum that any of the particles in the final state can have. The momenta have been calculated using the averaged central mass values, without taking into account the widths of the resonances.

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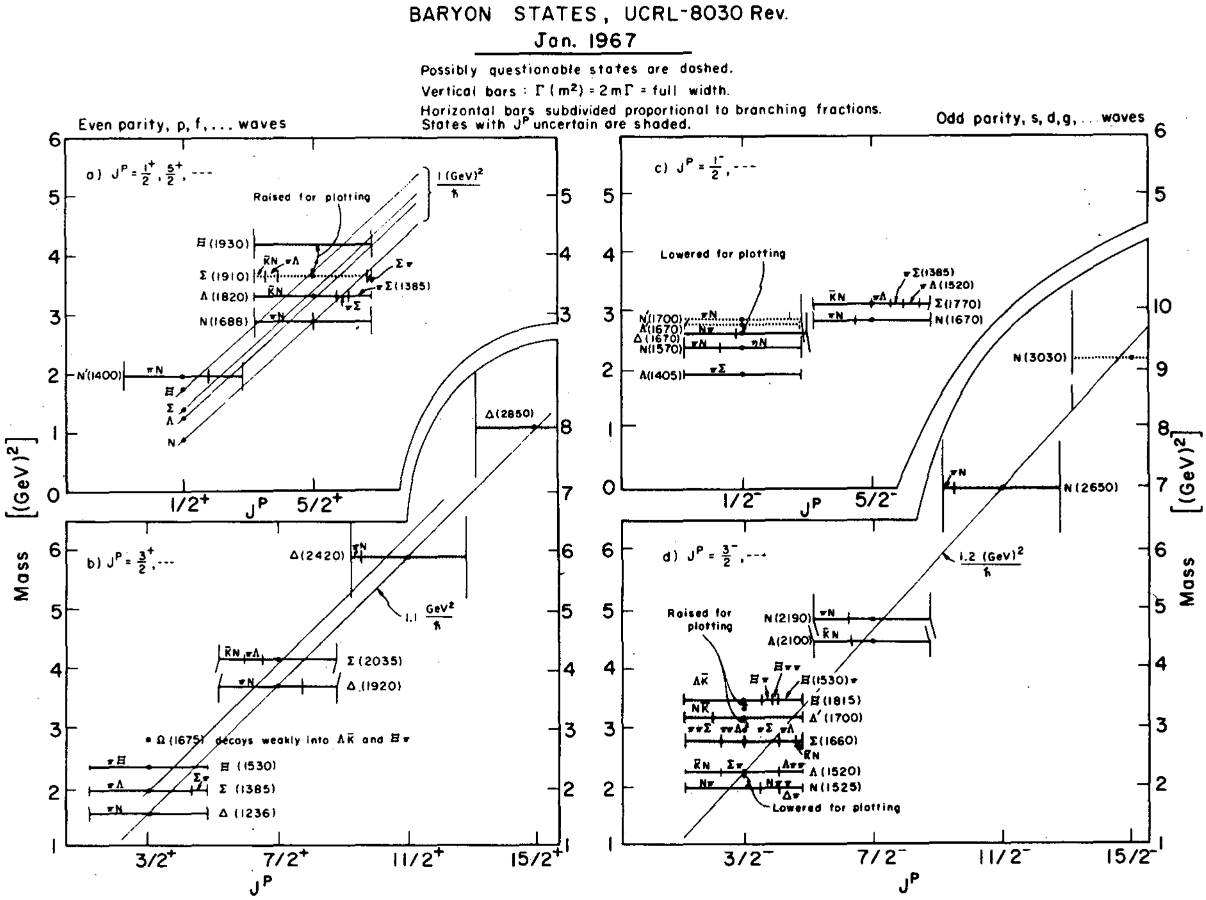
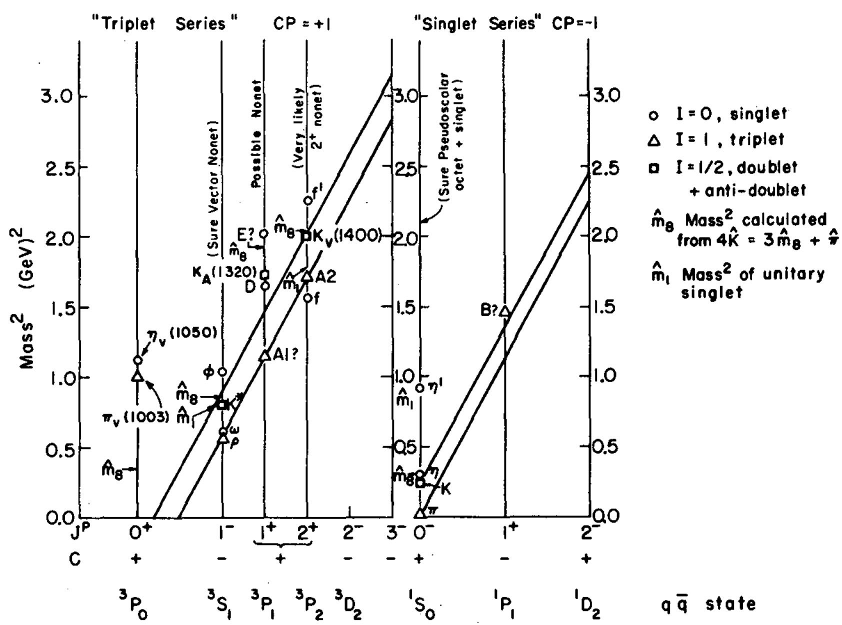


MUB-12336



MUB-8630

Special Relativity

Notation. 4-vector in c.m. $p = (w, \vec{p})$; in lab $P = (W, \vec{P})$, $T = W - m$.
Solid-angle element $d\omega = 2\pi d\cos\theta$; $d\Omega = 2\pi d\cos\Theta$.
$p^2 = w^2 - \vec{p}^2 = m^2$ is an invariant. Cross section σ is invariant.

Lorentz Transformation

$$\begin{pmatrix} w \\ p_x \\ p_y \\ p_z \end{pmatrix} = \begin{pmatrix} \bar\gamma & -\bar\eta & 0 & 0 \\ -\bar\eta & \bar\gamma & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} W \\ P_x \\ P_y \\ P_z \end{pmatrix}$$

If θ and Θ are measured with respect to the transformation axis x,

$$\frac{p_\perp}{p_x} = \tan\theta = \frac{P\sin\Theta}{-\bar\eta W + \bar\gamma P\cos\Theta} . \qquad (1)$$

If particle 1 is beam, 2 is target, $(W_2, \vec{P}_2) = (m_2, \vec{0})$ and
$\bar\gamma = (W_1 + m_2)/\sqrt{s}$, $\bar\eta \equiv \bar\gamma\bar\beta = |\vec{P}_1| / \sqrt{s}$, $|\vec{p}_1| = |\vec{p}_2| = \bar\eta m_2 = |\vec{P}_1| m_2/\sqrt{s}$. (2)
For $m_1 = m_2$, $\bar\gamma^2 = 1 + T_1/2m_1$.

Invariants. Notation: $1 + 2 \to 1' + 2'$.

$s = (p_1 + p_2)^2 = m_1^2 + m_2^2 + 2(w_1 w_2 - \vec{p}_1 \cdot \vec{p}_2)$ (3)

$t = (p_i' - p_i)^2 = m_i^2 + m_i'^2 - 2(w_i w_i' - \vec{p}_i \cdot \vec{p}_i')$ $(i = 1, 2)$ (4)

$u = (p_1' - p_2)^2 = (p_2' - p_1)^2$ (5)

General relation: $s + t + u = m_1^2 + m_1'^2 + m_2^2 + m_2'^2$. (6)

In lab system $P_2 = (m_2, \vec{0})$, and writing $W = m + T$

$s = m_1^2 + m_2^2 + 2W_1 m_2 = (m_1 + m_2)^2 + 2T_1 m_2$ (3, lab)

$t = m_2^2 + m_2'^2 - 2W_2' m_2 = (m_2 - m_2')^2 - 2T_2' m_2$ (4, lab)

In c.m. system $dt = +2|\vec{p}_i|\,|\vec{p}_i'|\, d\cos\theta$ (4, cm)

For elastic scattering $(m_1 = m_1', m_2 = m_2')$, (4) in c.m. simplifies to

$$\left.\begin{matrix} t \\ u \end{matrix}\right\} = -2\vec{p}^2(1 \mp \cos\theta) = -4\vec{p}^2 \left\{\begin{matrix} \sin^2\theta/2 \\ \cos^2\theta/2 \end{matrix}\right. \qquad (4, el)$$

For elastic scattering, using (4, lab), (4, el), and (2),

$$T_2' = \frac{2\vec{P}_1^2 m_2}{s} \sin^2\left(\frac{\theta}{2}\right) \quad \text{(useful for calculating δ-ray energies).} \qquad (7)$$

Two-Body States. Energies and momenta in c.m.

$$w_1 = \frac{s + m_1^2 - m_2^2}{2\sqrt{s}}, \quad \vec{p}_1^2 = \vec{p}_2^2 = \frac{1}{4s}\,[s - (m_1 + m_2)^2]\,[s - (m_1 - m_2)^2] . \qquad (8)$$

3- and 4-Body States. Let $m_{ij}^2 = (p_i + p_j)^2$, etc., then

$$\sum_{i<j} m_{ij}^2 = \Sigma m_i^2 + m_{123}^2 = \text{const.} \quad (i, j = 1, 2, 3) \text{ (follows from (6)).} \qquad (9)$$

$$\left.\begin{matrix} \sum_{i<j} m_{ij}^2 = 2\Sigma m_i^2 + m_{1234}^2 = \text{const.} \\ \sum_{i<j<k} m_{ijk}^2 = \Sigma m_i^2 + 2m_{1234}^2 = \text{const.} \end{matrix}\right\} (i, j, k = 1, 2, 3, 4.) \qquad (10)$$

R_n, Invariant Volume in n-Body Momentum Space

A useful invariant is $\int d^4p\, \delta(p^2 - m^2) = \frac{d^3\vec{p}}{2w} = \frac{\vec{p}^2 d|\vec{p}| d\omega}{2w} = \frac{1}{2}|\vec{p}|\, dw\, d\omega$.

$R_2 = \pi|\vec{p}_1|/\sqrt{s}$, $R_3 = \pi^2 \int dw_1 dw_2 = (\pi^2/4s)\int dm_{12}^2\, dm_{23}^2$ (using c.m. quantities)

Recurrence Relation for Factoring R_n (see e.g., Hagedorn, p. 93[a])

Write $N \to 1, 2, \cdots k, k+1, \cdots n$ (R_n)
as $N \to K, k+1, \cdots n$ (R_{n-k+1}); $K \to 1, 2, \cdots k$ (R_k)
then $R_n = \int dM_K^2 R_k R_{n-k+1}$

Cross Section (or Decay Rate)

For $1 + 2 \to n$ particles (or $1 \to n$ particles)

$\sigma F = |M|^2 R_n$ (or $\Gamma w_1 = |M|^2 R_n$)

where M is an invariant matrix element.

F is (Møller's) invariant flux factor, $F^2 = (p_1 p_2)^2 - m_1^2 m_2^2$.

In every system where $\vec{p}_1$ and $\vec{p}_2$ are collinear, $F = w_1 w_2 |\vec{v}_1 - \vec{v}_2|$ $(\vec{v} = \vec{p}/w)$.

If particle 1 is beam, 2 is target $(\vec{P}_2 = 0)$, $F = |\vec{P}_1| m_2 = |\vec{p}_1|\sqrt{s}$ [cf. (2)].

The rate (= number per unit 4-dimensional volume $d^4r = dt\, d^3\vec{r}$) is
$d^4N/d^4r = \sigma\, \rho_1 \rho_2 |\vec{v}_1 - \vec{v}_2|$. ρ_i = volume density of particles $(i = 1, 2)$.

a. R. Hagedorn, Relativistic Kinematics, (W. A. Benjamin, New York, 1964).

C. M. Energy and Momentum vs Beam Momentum of e, π, K, or p on p

$\mu d\mu = m_p dE = m_p v_{beam, lab}\, dp \approx m_p dp$

P(LAB) (MEV/C)	INVARIANT MASS (MEV) ep	πp	Kp	pp	P(CMS) (MEV/C) ep	πp	Kp	pp
0	939	1078	1432	1877	0	0	0	0
20	958	1079	1432	1877	20	17	13	10
40	977	1083	1433	1877	38	35	26	20
60	996	1089	1434	1877	56	52	39	30
80	1015	1096	1436	1878	74	68	52	40
T(PI) = PLAB - 59 MEV								
100	1033	1105	1439	1879	91	85	65	50
120	1051	1116	1441	1880	107	101	78	60
140	1069	1127	1445	1882	123	117	91	70
160	1087	1139	1449	1883	138	132	104	80
180	1104	1152	1453	1885	153	147	116	90
T(PI) = PLAB - 92 MEV								
200	1121	1165	1457	1887	167	161	129	99
220	1137	1178	1462	1889	182	175	141	109
240	1154	1192	1468	1892	195	189	153	119
260	1170	1206	1474	1894	209	202	166	129
280	1186	1219	1480	1897	222	215	178	138
T(PI) = PLAB - 107 MEV								
300	1201	1233	1486	1900	234	228	189	148
320	1217	1247	1493	1903	247	241	201	158
340	1232	1261	1500	1906	259	253	213	167
360	1247	1274	1507	1910	271	265	224	177
380	1262	1288	1514	1913	282	277	235	186
T(PI) = PLAB - 115 MEV								
400	1277	1302	1522	1917	294	288	247	196
420	1292	1315	1530	1921	305	300	258	205
440	1306	1329	1538	1925	316	311	268	214
460	1320	1342	1546	1929	327	322	279	224
480	1335	1356	1554	1933	337	332	290	233
T(PI) = PLAB - 120 MEV								
500	1349	1369	1563	1938	348	343	300	242
520	1362	1382	1572	1943	358	353	310	251
540	1376	1395	1580	1947	368	363	321	260
560	1390	1408	1589	1952	378	373	331	269
580	1403	1421	1598	1957	388	383	341	278
T(PI) = PLAB - 123 MEV								
600	1416	1434	1607	1962	397	393	350	287
620	1430	1446	1616	1967	407	402	360	296
640	1443	1459	1625	1973	416	412	370	304
660	1456	1472	1634	1978	425	421	379	313
680	1468	1484	1644	1984	434	430	388	322
T(PI) = PLAB - 125 MEV								
700	1481	1496	1653	1989	443	439	397	330
720	1494	1509	1662	1995	452	449	406	339
740	1506	1521	1671	2001	461	457	415	347
760	1519	1533	1681	2007	470	465	424	355
780	1531	1545	1690	2013	478	474	433	364
T(PI) = PLAB - 127 MEV								
800	1543	1557	1699	2019	486	482	442	372
820	1555	1569	1709	2025	495	490	450	380
840	1567	1580	1718	2031	503	499	459	388
860	1579	1592	1728	2037	511	507	467	396
880	1591	1604	1737	2043	519	515	475	404
T(PI) = PLAB - 129 MEV								
900	1603	1615	1747	2049	527	523	483	412
920	1615	1627	1756	2056	535	531	492	420
940	1626	1638	1765	2062	542	538	500	428
960	1638	1649	1775	2069	550	546	508	435
980	1649	1661	1784	2075	558	554	515	443
T(PI) = PLAB - 130 MEV								
1000	1660	1672	1794	2082	565	561	523	451
1020	1672	1683	1803	2088	573	569	531	458
1040	1683	1694	1812	2095	580	576	538	466
1060	1694	1705	1822	2102	587	583	546	473
1080	1705	1716	1831	2108	594	591	553	481
T(PI) = PLAB - 131 MEV								
1100	1716	1726	1840	2115	601	598	561	488
1120	1727	1737	1850	2122	609	605	568	495
1140	1738	1748	1859	2129	616	612	575	502
1160	1748	1758	1868	2135	622	619	583	510
1180	1759	1769	1877	2142	629	626	590	517
T(PI) = PLAB - 131 MEV								
1200	1770	1780	1887	2149	636	633	597	524
1220	1780	1790	1896	2156	643	639	604	531
1240	1791	1800	1905	2163	650	646	611	538
1260	1801	1811	1914	2170	656	653	618	545
1280	1812	1821	1923	2177	663	660	624	552
T(PI) = PLAB - 132 MEV								
1300	1822	1831	1932	2184	669	666	631	559
1320	1832	1841	1941	2191	676	673	638	565
1340	1843	1851	1950	2198	682	679	645	572
1360	1853	1862	1959	2205	689	685	651	579
1380	1863	1872	1968	2212	695	692	658	585
T(PI) = PLAB - 133 MEV								

P(LAB) (MEV/C)	INVARIANT MASS (MEV) ep	πp	Kp	pp	P(CMS) (MEV/C) ep	πp	Kp	pp
1400	1873	1881	1977	2219	701	698	664	592
1420	1883	1891	1986	2226	708	704	671	599
1440	1893	1901	1995	2233	714	711	677	605
1460	1903	1911	2004	2240	720	717	684	612
1480	1912	1921	2013	2247	726	723	690	618
T(PI) = PLAB - 133 MEV								
1500	1922	1930	2022	2254	732	729	696	624
1520	1932	1940	2031	2261	738	735	702	631
1540	1942	1950	2039	2268	744	741	709	637
1560	1951	1959	2048	2275	750	747	715	643
1580	1961	1969	2057	2282	756	753	721	650
T(PI) = PLAB - 133 MEV								
1600	1970	1978	2065	2289	762	759	727	656
1620	1980	1988	2074	2296	768	765	733	662
1640	1989	1997	2083	2304	773	770	739	668
1660	1999	2006	2091	2311	779	776	745	674
1680	2008	2016	2100	2318	785	782	751	680
T(PI) = PLAB - 134 MEV								
1700	2018	2025	2109	2325	791	788	756	686
1720	2027	2034	2117	2332	796	793	762	692
1740	2036	2043	2126	2339	802	799	768	698
1760	2045	2053	2134	2346	807	805	774	704
1780	2054	2062	2143	2353	813	810	779	710
T(PI) = PLAB - 134 MEV								
1800	2064	2071	2151	2360	818	816	785	716
1820	2073	2080	2159	2367	824	821	791	721
1840	2082	2089	2168	2374	829	827	796	727
1860	2091	2098	2176	2381	835	832	802	733
1880	2100	2107	2184	2388	840	837	808	739
T(PI) = PLAB - 134 MEV								
1900	2108	2115	2193	2395	845	843	813	744
1920	2117	2124	2201	2402	851	848	818	750
1940	2126	2133	2209	2409	856	853	824	756
1960	2135	2142	2217	2416	861	859	829	761
1980	2144	2150	2226	2423	867	864	835	767
T(PI) = PLAB - 135 MEV								
2000	2153	2159	2234	2430	872	869	840	772
2020	2161	2168	2242	2437	877	874	845	778
2040	2170	2176	2250	2444	882	879	851	783
2060	2179	2185	2258	2451	887	885	856	789
2080	2187	2194	2266	2458	892	890	861	794
T(PI) = PLAB - 135 MEV								
2100	2196	2202	2274	2465	897	895	866	799
2120	2204	2211	2282	2472	902	900	872	805
2140	2213	2219	2290	2479	907	905	877	810
2160	2221	2227	2298	2486	912	910	882	815
2180	2230	2236	2306	2493	917	915	887	821
T(PI) = PLAB - 135 MEV								
2200	2238	2244	2314	2500	922	920	892	826
2220	2246	2253	2322	2507	927	925	897	831
2240	2255	2261	2330	2514	932	930	902	836
2260	2263	2269	2338	2520	937	934	907	841
2280	2271	2277	2346	2527	942	939	912	846
T(PI) = PLAB - 135 MEV								
2300	2280	2286	2353	2534	947	944	917	852
2320	2288	2294	2361	2541	951	949	922	857
2340	2296	2302	2369	2548	956	954	927	862
2360	2304	2310	2377	2555	961	959	932	867
2380	2312	2318	2384	2561	966	963	937	872
T(PI) = PLAB - 135 MEV								
2400	2320	2326	2392	2568	970	968	941	877
2420	2328	2334	2400	2575	975	973	946	882
2440	2336	2342	2407	2582	980	977	951	887
2460	2344	2350	2415	2589	984	982	956	892
2480	2352	2358	2423	2595	989	987	960	897
T(PI) = PLAB - 136 MEV								
2500	2360	2366	2430	2602	994	991	965	901
2520	2368	2374	2438	2609	998	996	970	906
2540	2376	2382	2445	2616	1003	1001	975	911
2560	2384	2390	2453	2622	1007	1005	979	916
2580	2392	2398	2460	2629	1012	1010	984	921
T(PI) = PLAB - 136 MEV								
2600	2400	2405	2468	2636	1017	1014	988	926
2620	2408	2413	2475	2643	1021	1019	993	930
2640	2415	2421	2483	2649	1025	1023	998	935
2660	2423	2429	2490	2656	1030	1028	1002	940
2680	2431	2436	2498	2663	1034	1032	1007	944
T(PI) = PLAB - 136 MEV								
2700	2439	2444	2505	2669	1039	1037	1011	949
2720	2446	2452	2512	2676	1043	1041	1016	954
2740	2454	2459	2520	2682	1048	1045	1020	958
2760	2462	2467	2527	2689	1052	1050	1025	963
2780	2469	2474	2534	2696	1056	1054	1029	968
T(PI) = PLAB - 136 MEV								

P(LAB) (GEV/C)	INVARIANT MASS (GEV) πp/ep	Kp	pp	P(CMS) (GEV/C) πp/ep	Kp	pp
3.0	2.56	2.61	2.77	1.10	1.08	1.02
3.2	2.63	2.68	2.83	1.14	1.12	1.06
3.4	2.70	2.75	2.89	1.18	1.16	1.10
3.6	2.77	2.82	2.96	1.22	1.20	1.14
3.8	2.83	2.88	3.02	1.26	1.24	1.18
T(PI) = PLAB - .137 GEV						
4.0	2.90	2.95	3.08	1.29	1.27	1.22
4.2	2.96	3.01	3.14	1.33	1.31	1.26
4.4	3.03	3.07	3.19	1.36	1.34	1.29
4.6	3.09	3.13	3.25	1.40	1.38	1.33
4.8	3.15	3.19	3.31	1.43	1.41	1.36
T(PI) = PLAB - .138 GEV						
5.0	3.21	3.25	3.36	1.46	1.44	1.40
5.2	3.27	3.31	3.42	1.49	1.48	1.43
5.4	3.32	3.36	3.47	1.53	1.51	1.46
5.6	3.38	3.42	3.52	1.56	1.54	1.49
5.8	3.43	3.47	3.58	1.59	1.57	1.52
T(PI) = PLAB - .138 GEV						
6.0	3.49	3.52	3.63	1.61	1.60	1.55
6.2	3.54	3.58	3.68	1.64	1.63	1.58
6.4	3.59	3.63	3.73	1.67	1.65	1.61
6.6	3.65	3.68	3.78	1.70	1.68	1.64
6.8	3.70	3.73	3.83	1.73	1.71	1.67
T(PI) = PLAB - .138 GEV						
7.0	3.75	3.78	3.87	1.75	1.74	1.70
7.2	3.80	3.83	3.92	1.78	1.76	1.72
7.4	3.85	3.88	3.97	1.81	1.79	1.75
7.6	3.89	3.93	4.02	1.83	1.82	1.78
7.8	3.94	3.97	4.06	1.86	1.84	1.80
T(PI) = PLAB - .138 GEV						
8.0	3.99	4.02	4.11	1.88	1.87	1.83
8.2	4.04	4.07	4.15	1.91	1.89	1.85
8.4	4.08	4.11	4.20	1.93	1.92	1.88
8.6	4.13	4.16	4.24	1.95	1.94	1.90
8.8	4.17	4.20	4.29	1.98	1.96	1.93
T(PI) = PLAB - .138 GEV						
9.0	4.22	4.25	4.33	2.00	1.99	1.95
9.2	4.26	4.29	4.37	2.03	2.01	1.97
9.4	4.31	4.33	4.41	2.05	2.03	2.00
9.6	4.35	4.38	4.46	2.07	2.06	2.02
9.8	4.39	4.42	4.50	2.09	2.08	2.04
T(PI) = PLAB - .139 GEV						
10.0	4.43	4.46	4.54	2.12	2.10	2.07
10.5	4.54	4.57	4.64	2.17	2.16	2.12
11.0	4.64	4.67	4.74	2.22	2.21	2.18
11.5	4.74	4.77	4.84	2.28	2.26	2.23
12.0	4.84	4.86	4.93	2.33	2.31	2.28
T(PI) = PLAB - .139 GEV						
12.5	4.94	4.96	5.03	2.38	2.36	2.33
13.0	5.03	5.05	5.12	2.43	2.41	2.38
13.5	5.12	5.15	5.21	2.47	2.46	2.43
14.0	5.21	5.24	5.30	2.52	2.51	2.48
14.5	5.30	5.32	5.39	2.57	2.56	2.53
T(PI) = PLAB - .139 GEV						
15.0	5.39	5.41	5.47	2.61	2.60	2.57
15.5	5.48	5.50	5.56	2.66	2.65	2.62
16.0	5.56	5.58	5.64	2.70	2.69	2.66
16.5	5.64	5.67	5.72	2.74	2.73	2.70
17.0	5.73	5.75	5.81	2.78	2.77	2.75
T(PI) = PLAB - .139 GEV						
17.5	5.81	5.83	5.89	2.83	2.82	2.79
18.0	5.89	5.91	5.97	2.87	2.86	2.83
18.5	5.97	5.99	6.04	2.91	2.90	2.87
19.0	6.05	6.07	6.12	2.95	2.94	2.91
19.5	6.12	6.14	6.20	2.99	2.98	2.95
T(PI) = PLAB - .139 GEV						
20.0	6.20	6.22	6.27	3.03	3.02	2.99
21.0	6.35	6.37	6.42	3.10	3.09	3.07
22.0	6.49	6.51	6.56	3.18	3.17	3.14
23.0	6.64	6.66	6.70	3.25	3.24	3.22
24.0	6.78	6.79	6.84	3.32	3.31	3.29
T(PI) = PLAB - .139 GEV						
25.0	6.91	6.93	6.98	3.39	3.38	3.36
26.0	7.05	7.07	7.11	3.46	3.45	3.43
27.0	7.18	7.20	7.24	3.53	3.52	3.50
28.0	7.31	7.33	7.37	3.59	3.59	3.56
29.0	7.44	7.45	7.50	3.66	3.65	3.63
T(PI) = PLAB - .139 GEV						
30.0	7.56	7.58	7.62	3.72	3.71	3.69
35.0	8.16	8.17	8.21	4.02	4.02	4.00
40.0	8.72	8.73	8.77	4.31	4.30	4.28
45.0	9.24	9.25	9.29	4.57	4.56	4.55
50.0	9.73	9.74	9.78	4.82	4.81	4.80
T(PI) = PLAB - .139 GEV						

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THEORETICAL PHYSICS RESEARCH

Geoffrey F. Chew in charge

I. SUBNUCLEAR PHYSICS

Work with P. V. Landshoff on parastatistics and identical particles has been completed.[1] In the first part of the work an equivalence was shown between various theories involving paraparticles and theories involving only ordinary particles; the parastatistics commutation relations were shown to be merely a complicated way of introducing particles that are statistically distinct but dynamically indistinguishable. In the second part of the work a unified theory of identical particles was developed. Heretofore, theories of identical particles have been couched either in the language of second quantized field theory, which leads to parastatistics, or in the language of ordinary quantum mechanics, which leads to permutation symmetries. These alternatives are incompatible except for fermions and bosons. Our unified S-matrix theory of identical particles encompasses both approaches. Its central feature is the identification of particle permutations as the fundamental observable in systems consisting of identical particles. (Henry P. Stapp)

Discontinuity equations have been derived for all singularities of multiparticle scattering functions that enter the portion of the physical region lying below the four-particle threshold.[2] These equations, which are precise statements of the Cutkosky rules, are calculated directly from the unitarity equations. The only analyticity properties used are those obtained from the S-matrix macroscopic causality condition. (Joseph Coster and Henry P. Stapp)

A previous study[3] of the structure of the left-hand discontinuity of the full partial-wave amplitude has been extended. Analyticity and unitarity were exploited in a dispersion-relation approach, and the results applied to some low partial-wave p-p scattering amplitudes. (Judith Binstock)

Work to convert the Bergman-Weil formula to a form that will provide a Mandelstam-type integral representation for arbitrary n-particle scattering functions is in progress. One problem is the complicated topology of the mass shell. In particular, for $n \geqslant 6$, the mass shell is an analytic variety that has non-Euclidean singular points. This problem has been solved and general formulas obtained for the idealized case with only normal threshold cuts. Formulas for the general case are being sought. (Jared Wright, National Science Foundation Predoctoral Fellow, and Henry P. Stapp)

A dispersion relation representation of the full off-energy-shell partial-wave amplitude has been developed. This representation expresses the full-off-shell amplitude in terms of the half-off-shell amplitudes and serves as a convenient basis for approximations. (Thomas R. Mongan)

It has been shown that the assumptions of maximal analyticity of first-degree and fixed-t power behavior in general imply a lower bound for the scattering amplitude at a fixed angle. The fixed angle lower bound takes for form $\exp[-C(z_s)s^{\gamma}\ell n\, s]$, where z_s is the cosine of the s-channel scattering angle, and $C(z_s)$ and γ are positive. The precise value of γ depends on the specific assumptions made about the fixed-t bound of the scattering amplitude. In particular, the assumptions made by Cerulus and Martin correspond to $\gamma = 1/2$, and for the case of a linearly rising trajectory, $\gamma = 1$. Furthermore, we obtain a finite lower bound at $z_s = 0$, which heretofore was given to be zero. (C. B. Chiu and C. I. Tan)

Work is currently under way on a study of form factors and scattering amplitudes which saturate the Martin-Jaffe bound. Form factors of the form $\exp[-|t|^{\frac{1}{2}}]$ are used as inputs in dynamical bound-state calculations, and self-consistency conditions relating the resulting mass spectrum and the form factor are examined. The compatibility of such form factors to scattering amplitudes with ever-rising Regge trajectories is also under investigation. (John Harte, AEC Fellow)

It has been proved[4] that in the usual

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1. P. V. Landshoff and H. P. Stapp, Identical Particles and Parastatistics, UCRL-17310, January 4, 1967; Ann. Phys., to be published.
2. Joseph Coster and Henry P. Stapp, Physical-Region Discontinuity Equations for Many-Particle Scattering Amplitudes. I, UCRL-17484, April 13, 1967; submitted to J. Math. Phys.
3. J. Binstock, Ann. Phys. (N.Y.) 35, 435 (1966).
4. Huan Lee, Nonexistence of Self-Conjugate Particles with Half-Integral Isospin, UCRL-17513 April 17, 1967; submitted to Phys. Rev. Letters.

local field theory of particles one cannot, for any value of ordinary spin, construct fields corresponding to particles of a self-conjugate multiplet of half-integral isospin (SMHI). An analogous result is obtained within the analytic S-matrix framework, in which the requirement of isospin invariance and crossing symmetry precludes the existence of SMHI particles of any spin. Interesting physical implications and generalizations of this result to higher internal symmetry have been discussed. (Huan Lee)

The set of variables introduced by Toller[5] for the high-energy description of scattering amplitudes has been generalized to the case of asymptotic behavior in several variables, for an arbitrary production process. A precise formulation of the multiple Regge-pole hypothesis has been developed. (N. F. Bali, G. F. Chew, and A. Pignotti*)

The asymptotic behavior of scattering amplitudes on unphysical sheets is being studied. Special attention has been paid to the effect of unitarity as a simultaneous condition in both the s and t channels. It is found that the amplitude on the first unphysical sheet contains terms corresponding to the usual Amati-Fubini-Stanghellini (AFS) cut.[6] It is also found that a new type of AFS cut exists if a Regge trajectory does not go to $-\infty$ fast enough when the energy of the Regge pole goes to $-\infty$. This new cut, if it exists, will be the leading singularity in the angular-momentum plane when the momentum transfer is sufficiently large. Work is still in progress. (Chung-I Tan)

A novel technique has been used to construct the scattering Green's function for the case of a central potential that satisfies rather conventional conditions. The method leads quite naturally to a representation of the Green's function in terms of Regge wave functions and a "background" term. When the Green's function is used to construct the scattering wave function and amplitude, this method yields the original Regge result. The extension given by Mandelstam in which the background integral is pushed into the negative ℓ plane by any finite amount has also been obtained. This work is described in UCRL-17344.[7] (Joseph V. Lepore and R. J. Riddell, Jr.)

Earlier derivations of the analyticity properties of helicity amplitudes have been based upon the ingenious but complicated method of requiring consistency with certain crossing relations. Now a direct derivation from basic analyticity properties has been obtained.[8] (Henry P. Stapp)

In a recent investigation,[9] new properties and sum rules have been found for SU(2) crossing-matrix elements, and a simple method of calculating the crossing matrices of rank $\leqslant 4$ presented. Isospin crossing relations were discussed and errors in two previous treatments pointed out. Physical implications of certain inequalities among elastic crossing matrix elements were also discussed. (Huan Lee)

Work is continuing on the review article dealing with Regge scattering analyses and the analytic structure of crossing relations described in the last progress report. The scope of the paper is being broadened by inclusion of these properties for cases in which particles of arbitrary mass and spin are involved. (Joseph V. Lepore and R. J. Riddell, Jr.)

Work is in progress on the physical interpretation of unitary irreducible representations of covering groups of the Lorentz group. These representations have been employed recently in the harmonic analysis of scattering amplitudes in terms of momentum-transfer parameters and provide a new approach to understanding the content of Regge-pole theory. (Graham Tindle, NATO Fellow)

It has been shown[10] that, with some simple assumptions about the behavior of the discontinuity of the cut in the angular-momentum plane (associated with the simultaneous exchange of the ρ and the P trajectories),

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5. M. Toller, Nuovo Cimento 37, 631 (1965).
* On leave from Consejo Nacional de Investigaciones Científicas y Técnicas of Argentina.
6. D. Amati, S. Fubini, and A. Stanghellini, Phys. Letters 1, 29 (1962); Nuovo Cimento 26, 896 (1962).
7. J. V. Lepore and R. J. Riddell, Jr., The Scattering Green's Function and Regge Poles, UCRL-17344, January 4, 1967; submitted to Nuovo Cimento.
8. H. P. Stapp, Analyticity Properties of Helicity Amplitudes, UCRL-17429; submitted to the Phys. Rev.
9. Huan Lee, On the Isospin Crossing Matrix, UCRL-17485, March 30, 1967; submitted to J. Math. Phys.
10. C. B. Chiu and J. Finkelstein, Suggestive Features in πN Charge-Exchange Polarization Associated with Regge Cuts, Nuovo Cimento (to be published).

the high energy πN charge-exchange polarization should have the following features: It has a zero whose position depends on the energy near the forward direction [say with $|t| < 1$ $(GeV/c)^2$]. In the t region between $t = 0$ and the position of this zero polarization, the polarization decreases with energy; beyong this region, the polarization increases with energy. Consistent with all the other available πN data, the present charge-exchange polarization and differential-cross-section data can be fitted by a small ρ-P cut contribution in addition to the ρ contribution, with the ρ trajectory choosing either sense or nonsense states at $\alpha_\rho = 0$. If the ρ trajectory chooses the nonsense state, the cross-over effect observed in the high-energy $\pi^{\pm}p$ differential cross section can be explained naturally without introducing a zero in the helicity-nonflip amplitude of the ρ, as is necessary in the present pure Regge-pole model. (C. B. Chiu and J. Finkelstein)

An argument has been developed, on the basis of a simple bootstrap model with indefinitely rising Regge trajectories, that asymptotically all trajectories should rise linearly with energy and should have the same slope.[11] (Shu-Yuan Chu and Chung-I Tan)

The effects of resonance width on production angular distributions have been considered. The forward minimum due to the mass-dependent physical boundary has been calculated and found to be negligible in all cases except double-resonance production at low energies. The effect of variation of residue functions with mass in the Regge-pole model has also been examined. It was found that exponential momentum-transfer dependence modified by a mass-dependent slope may produce radical departures from pure exponential behavior in the cross section. Various dynamical assumptions that restrict the mass dependence of residue functions are being studied. (Robert L. Thews)

An assumption made in previous proofs of the existence of daughter families as a consequence of Lorentz invariance has been shown to be unnecessary.[12] Previously it was known that a single Lorentz pole corresponded to a family of Regge poles, and it was assumed that the Lorentz poles did not themselves occur in families, since it was feared that this "counter conspiracy" might correspond to a single Regge pole. It has now been shown that infinite Regge families must exist, whether or not the Lorentz poles occur in families. (J. Finkelstein and J. M. Wang)

By an explicit mapping procedure, a meaning has been given to approximate zero-momentum-transfer symmetry for analytic S-matrix elements containing a sufficiently large number of particles.[13] The difficulty in formulating the symmetry for two-particle-to-two particle reactions has been elucidated. (Naren F. Bali, Geoffrey F. Chew, and Alberto Pignotti, with James S. Ball from UCLA)

A sum rule of the "superconvergence" type relating the t-channel meson spectrum to the s-channel baryon spectrum was derived for πN scattering. The sum rule is satisfied quite well numerically. (Douglas S. Beder and Jerome Finkelstein)

The response of the decuplet masses to octet perturbations of the meson and baryon masses and couplings has been studied in an N/D model of baryon-meson scattering,[14] and it was found that the equal- mass spacing of the decuplet is satisfied in the model, even for large values of the symmetry breaking. The numerical inaccuracy of several forms of perturbation theory indicates that the physical baryon masses represent a large symmetry breaking in the calculation of the decuplet; for physical baryon and meson masses and SU(3) symmetric couplings, the first-order mass shift is about one-half the value given by the exact solution of the model. This suggests that the octet output of the masses is specially enhanced in the exact solution of the model, just as in the first-order Dashen-Frautschi theory.[15] The rate at which the first-order formulas become accurate as the degenerate mass of the external particles is increased was examined. The octet sum rules of S-matrix elements break down quickly as the octet perturbations are increased. (Richard Slansky)

In collaboration with Mr. R. Chu of Tufts University, a study of the effect of intra-multiplet mass differences on symmetry relations among scattering amplitudes as predicted by SU(3) has been completed. This

11. Shu-Yuan Chu and Chung-I Tan, The High Energy Behavior of Regge Trajectories in a Bootstrap Model, UCRL-17511, April 19, 1967; submitted to Phys. Rev. Letters.
12. J. Finkelstein and J. M. Wang, A Proof of the Lorentz Pole Hypothesis, UCRL-17500, April 1967, submitted to Phys. Rev. Letters.
13. Naren F. Bali, James S. Ball, Geoffrey F. Chew, and Alberto Pignotti, Analytic S-Matrix Approach to Zero-Momentum-Transfer Symmetry, UCRL-17491, March 6, 1967, submitted to Phys. Rev.
14. Richard C. Slansky, On the Equal Mass Spacing of the Decuplet of $J^P = \frac{3}{2}^+$ Baryons (Ph. D. thesis), UCRL-17450, March 15, 1967.
15. R. F. Dashen and S. C. Frautschi, Phys. Rev. 137, B1331 (1965).

extends an earlier potential-model calculation[16] to a more realistic case in which the matrix ND^{-1} representation and determinantal approximation are used, following the work of Wali and Warnock,[17] to calculate the single-baryon exchange contribution to the $P_{3/2}$ partial wave in meson-baryon scattering. We find violations of the two SU(3) relations studied, in agreement with the earlier work. These violations are very severe near threshold and remain appreciable to quite high energy, regardless of how one compares data from different reactions. In addition, we note that with the usual D/F ratio, the admittedly crude model predicts a $P_{3/2}$ contribution near threshold to the cross sections for $\pi^+p \to K^+\Sigma^+$ and $K^-p \to \Xi^0 K^0$ which is an order of magnitude larger than the experimental total cross sections. (Allen E. Everett, Tufts University, Medford, Mass.)

A study has been made of the magnitude of the corrections to the ND^{-1} method, in which one keeps only the first Born-approximation contribution to the left-hand cut which arises from successive Mandelstam iterations. We proceed by constructing a fictitious potential, $V_f(E, r)$, such that the approximate partial-wave solutions to the scattering from the actual potential $V(E, r)$ have the same left-hand cut as the exact scattering solutions from the potential $V(E, r) + V_f(E, r)$. We then compare the lowest-order contribution to V_f, V_{f2} (the part needed to cancel the second Born contribution of V) to V itself. As expected, the effect of V_{f2} will be negligible compared to that of V for sufficiently low energies, high angular momenta, or weak potentials. We examine two practical cases, $J = 1$ $\pi\pi$ scattering at the energy of the ρ with V approximated by ρ exchange, and $P_{3/2}$ πN scattering at the energy of the 33 resonance, with V approximated by N exchange. In both cases, we find the effect of V_{f2} is 30 to 40% of that of V, so that the usual ND^{-1} procedure might be expected to be qualitatively, but not quantitatively, correct. (Allen E. Everett, Tufts University, Medford, Mass.)

A model of the nucleon based on the Bethe-Salpeter equation has been used to investigate the response of the binding energy to small perturbations. Comparisons with the predictions of an N/D model were drawn, and it is shown that the effect of perturbations of the strong-interaction coupling constant may be better described by using off-shell dynamics. In this Bethe-Salpeter model neither the photon-exchange graph nor the feedback effect can explain the n-p mass difference, but if N^* exchange provides the attractive force to bind the nucleon, then radiative corrections to the $N^*N\pi$ vertex may explain the sign of $m_n - m_p$. Evidence is given for the predominance of pseudovector rather then pseudoscalar $NN\pi$ coupling. (John Harte, AEC Fellow)

Conditions for arriving at the static limit of the original Bethe-Salpeter (BS) equation have been examined, as an extension of previously reported work. To this end, the role of the relative-time variable in the BS equation has been studied. A close connection between this relative-time coordinate and the presence of antiparticles in the theory has been established. By a well-defined sequence of approximations, which are unjustified for the original marginally singular equation, we arrived at the "Chew-Low equations" in the "ladder approximation" (or Lee model in the $V\theta$ sector for a γ_5 type coupling). The nucleon recoil has been kept to first order in the nucleon kinetic energy, thus providing a natural cutoff in the otherwise supersingular problem. The integral equation we arrived at in this way is marginally singular. In order to have a vague justification of the approximations made, we also discussed the static limit for the BS equation with cutoff. The static equation we derived from here was solved numerically and its solutions were compared with those of the original BS equation for a range of values for the cutoff parameter and the case of weakly bound states. The results were also compared to a Blankenbecler-Sugar type of approximation to the BS equation. (Klaus D. Rothe)

Numerical study of the unequal-mass Bethe-Salpeter ladder equation continues. The method previously used (Rayleigh-Ritz), although successful for a large range of parameters, was not adequate for certain cases including very weakly bound systems and bound systems whose constituent particles have extremely different masses. (A more realistic set of trial functions would likely improve this.) To remedy this difficulty, we have extended the Schwinger to the unequal-mass situation variational principle as formulated by Schwartz and Zemach.[18] Preliminary results are quite encouraging. The Schwinger variational principle for the Schrödinger equation has been analytically continued to all ℓ for a particular (complete) set of trial functions. Convergence is rather fast, so this method may be promising for larger problems such as those with coupled channels and spin. (William B. Kaufmann)

16. A. E. Everett, Phys. Rev. 139, B1375 (1965).
17. K. C. Wali and R. L. Warnock, Phys. Rev. 135, B1358 (1964).
18. C. Schwartz and C. Zemach, Phys. Rev. 141, 1454 (1966).

A study has been made of the singularities of the Bethe-Salpeter and Schrödinger equation two-body scattering amplitudes in all off-shell variables. A numerical study of methods of finding phase shifts for these equations has been completed as a thesis. A letter describing a successful calculation of phase shifts from the Bethe-Salpeter differential equation using the above ideas has been prepared for publication. A variational method for calculating Regge trajectories was presented at the American Physical Society April meeting in Washington, D. C. (Richard Haymaker)

A study of Regge trajectories for two-channel processes in potential theory has been initiated. It is expected that some understanding will be obtained of the effect of higher thresholds and of the spin of the external particles; this could then be extended to relativistic situations. (N. F. Bali and Richard W. Haymaker)

The Regge trajectories for a superposition of two Yukawa potentials have been studied by using analytical and numerical methods.[19] The addition of a strong short-range repulsion to a long-range attraction gives rise to branch-points in the trajectory functions below threshold; these could have consequences in high-energy Regge-pole data fitting. (N. F. Bali,* Shu-Yuan Chu, Richard Haymaker and Chung-I Tan)

It is shown that the argument of Gribov and Pomeranchuk for the existence of fixed poles in the J plane at "nonsense" values of J goes through in the presence of cuts, even though their argument for an essential singularity then fails. Such poles have no effect on the asymptotic behavior but, in cases where the contribution of the third double-spectral function is large, they will invalidate both the Schwarz super-convergence relations and the presence of dips in the asymptotic region. A Regge trajectory will not choose sense or nonsense at a point where it passes through an integer of the wrong signature.[20] (S. Mandelstam and L. L. Wang)

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19. N. F. Bali, S. Y. Chu, R. W. Haymaker, and C. I. Tan, Regge Trajectories for Two Yukawa Potentials, UCRL-17475, April 3, 1967; submitted to Phys. Rev.
*Fellow of the Consejo Nacional de Investigaciones Científicas y Técnicas, Argentina while part of this work was completed.
20. L. L. Wang and S. Mandelstam, Gribov-Pomeranchuk Poles in Scattering Amplitudes, U. C.-Berkeley preprint.

Some mathematical questions of the solution of N/D equations by means of the determinantal approximation have been investigated. Two soluble models, "one-pole" and "two-pole", in which the left-hand cuts consist of delta functions were used to illustrate the method. The method was then applied to the $\pi\pi$ problem in s and p waves. It was found that in a small-cutoff theory the forces due to the exchange of the sigma (I = J = 0 $\pi\pi$ resonance) and rho (I = J = 1 $\pi\pi$ resonance) are not sufficiently strong to produce any output resonances if their experimental mass and width values are taken as input. However, when the rho width is increased some 20 to 30 times, a p-wave resonance does occur. If the cutoff is increased, the "critical input width" is correspondingly decreased. With no cutoff, the input critical width is about 400 MeV. These results are in general agreement with those obtained by David Atkinson using the matrix-inversion technique. The multichannel πN problem, in which the second contributing channel is the $\pi N \rightarrow \pi N^*$, will be investigated in this approximation. The formalism includes the solutions of a Muskhelishvili-Omnès problem together with a Frye-Warnock system. It is hoped that the 175-MeV "zero" as well as the 600-MeV Roper resonance will emerge from the calculation. (Kwok M. Ong)

The study of the Regge model for high-energy πp, pp, and $\bar{p}p$ elastic scattering at small momentum transfer, based on the assumed dominance of a few Regge poles in the crossed channel, has been completed. For πp scattering these poles are the P, P', and ρ; for pp and $\bar{p}p$, ignoring isospin dependence, they are P, P', and ω. This model fits a wide variety of data, including the differential cross sections that shrink for pp but not for πp or $\bar{p}p$, recent results from Brookhaven on total cross sections and ratios of the real to imaginary parts of the forward scattering amplitude, and also recent πp and pp polarization results. The factorization property of Regge poles was assumed in the model for the P and P' couplings and hence is tested by these fits to the data. (C. B. Chiu and R. J. Riddell, Jr., with William Rarita, U. C., Berkeley, and Roger J. N. Phillips, A. E. R. E., Harwell, England)

The differential cross sections for the reactions $pn \rightarrow np$ and $p\bar{p} \rightarrow n\bar{n}$ have been investigated. It is found that, besides the ρ and R trajectories, the π and B trajectories must be included. Various schemes suggested by four-dimensional symmetry have been investigated. It was found that the existence of various daughter trajectories does not suffice to explain the data, though the data can be fitted with a parity-doublet (of which the pion may or may not be a member). (Farzam Arbab and Jan W. Dash, NSF Predoctoral Fellow)

Work was begun on an attempt to understand polarization in the $\pi^- p \to \pi^0 n$ process at high energies in terms of branch points in the ρ trajectory for $t < 0$. A fit to the differential and total cross sections, and to the proton polarization was carried out, but results were inconclusive; more data is required. (N. F. Bali and Richard W. Haymaker)

The Regge-pole model for inelastic quasi-two-body processes has been investigated. Contributions to the spin-density matrix elements from exchange of known trajectories have been calculated, and some restrictions noted. An upper bound for the spin-density matrix element of the ρ^0, $|\mathrm{Re}\,\rho_{10}|$, in the process $\pi^- p \to \rho^0 n$ was obtained. The bound is clearly violated by experiment.[21] Further work on the quasi-two-body process is in progress, including an investigation of the decay correlations between two unstable final-state particles. (Gordon A. Ringland, Miller Postdoctoral Fellow, and Robert L. Thews)

The applicability of the Regge-resonance interference model to the πN data for pion incident laboratory momentum, P_L, below 6 GeV/c has been studied in collaboration with A. V. Stirling.[22] At $t = 0$, one can see that in the low-energy region ($P < 1$ GeV/c), the simple extrapolated Regge amplitudes (for both $I = 0$ and $I = 1$ states in the t channel) deviate significantly from nonresonating amplitudes obtained from the phase-shift analysis. On the other hand, for $P_L > 2$ GeV/c, both $\sigma_T(\pi^+ p)$ and $\sigma_T(\pi^- p)$ data can be fitted by this model.

For $P_L > 2$ GeV/c and $t \neq 0$, but near the forward direction, a simultaneous fit to various πN data indicates that a reasonable fit can be achieved for: (a) $\pi^- p$ charge-exchange differential cross section (dcs) data, (b) the $\pi^- p$ polarization data for $|t| < 1.5$ $(\mathrm{GeV}/c)^2$, and (c) $\pi^\pm p$ dcs data for $|t| < 1$ $(\mathrm{GeV}/c)^2$. There is a systematic discrepancy between the fit and the data for $\pi^+ p$ polarization at 2.5 GeV/c near $|t| = 0.5$ $(\mathrm{GeV}/c)^2$. It was shown that the fit to the $\pi^- p$ dcs at 180 deg can be achieved in a variety of ways. Thus the success in fitting these data can only be taken as suggestive evidence for the validity of the model. On the other hand, the backward $\pi^+ p$ dcs puts strenuous constraint on the interference model. We have not been able to achieve a solution that gives reasonable fits to the $\pi^+ p$ data in both the 8- and 2- to 3-GeV/c region; the validity of this model for this case has not been established. (C. B. Chiu)

Study of the dip-bump structure in the low energy $\pi^\pm p$ and $\bar{p}p$ elastic differential cross sections has been continued.[23] It is found that a zero in the helicity nonflip amplitude of the P' trajectory gives a natural explanation of this structure. The helicity nonflip amplitude of the P' trajectory vanishes at $\alpha_{P'} = 0$ if the P' trajectory chooses what is called the no-compensation mechanism. With this mechanism incorporated, a fit was obtained for the $\pi^\pm p$ dip-bump structure, and, additionally, to the high-energy $\pi^\pm p$ total and differential cross sections, the $\pi^\pm p$ polarizations and the $\pi^- p$ charge-exchange differential cross-section data. Consistent with this πp solution, the pp and $\bar{p}p$ total and differential cross section could also be fitted. The secondary maximum in the low energy $\bar{p}p$ differential cross section was reproduced. (C. B. Chiu, Shu-Yuan Chu, and Ling-Lie Wang)

A superposition of a Regge-pole exchange amplitude and direct channel resonances has been applied to forward $K^- p \to \pi^+ \Sigma^-$ scattering at energies from 1.8 to 2.9 GeV. Further improvements of this superposition model are being studied by an examination of the fits to πN data, and by a search for theoretical justifications. In particular, attempts to fit backward $\pi^+ p \to \pi^+ p$ scattering provide a severe test of any improved model. (Richard Brower)

The study of peripheral models involving meson-nucleon reactions leading to a four-body final state was continued, with particular reference to the predictions of the models for various three-particle invariant mass distributions. The predictions of a model with one two-particle resonance and one virtual nucleon in the intermediate state were obtained and compared in detail to experimental results consistent with diffraction scattering. The entire formalism assumed arbitrary values for the center-of-mass energy and all masses involved. Thus, the results were applied

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21. G. A. Ringland and R. L. Thews, Bound for Effective Polarization in ρ Production in a Regge-Pole Exchange Model, UCRL-17474, March 1967; submitted to Phys. Rev. Letters.
22. A. V. Stirling and C. B. Chiu, Remarks on the Regge-Resonance Model in πN Scattering, in preparation.
23. C. B. Chiu, S. Y. Chu, and L. L. Wang, Regge-Pole Model for πN and NN Secondary Maxima and the No-Compensation Mechanism, UCRL-17339, January 1967; submitted to Phys. Rev.

easily to a variety of different reactions at various energies.[24] (Ivan Kramer)

The study of the importance of t-channel exchange forces in pion-nucleon static-model calculations is completed.[25] For the soluble model considered, we find that these forces are very important and give sizable contributions to partial-wave superconvergence relations. (F. Landis Markley)

Work is in progress on a separable potential fit to the Livermore nucleon-nucleon scattering data for energies from 0 to 400 MeV. (Thomas R. Mongan)

A calculation of $\eta \rightarrow \pi^+\pi^-\pi^-\gamma$ is in progress, based on a vector dominance model of the decay, which has recently been observed experimentally at LRL. Comparison with the $\pi\pi\gamma$ and $\gamma\gamma$ decay modes will be obtained. (Douglas S. Beder)

A brief study was made of Coulomb effects in strong-interaction scattering, with regard to recent experiments at Brookhaven. One particular technique being used to evaluate Coulomb effects was found to be incorrect, but the study corroborates the validity of a second technique to calculate these effects. (Douglas S. Beder)

An attempt is under way to measure the pion electromagnetic form factor by analysis of the scattering of positive and negative pions on helium. Several formalisms have been studied, all seeking to exploit the fact that, since helium-4 is isoscalar, the strong pion-nucleus interaction is the same for both signs of charge. Any information on the pion form factor is then contained in the net electrostatic potential of the system. A program is in preparation to compute the differential cross sections expected, on the basis of previous mesic atom work. It is hoped that this will show the energies and angles for which the cross sections are most sensitive to the pion radius. (Tom Mottershead)

The question of symmetry-breaking corrections to the Σ^+ magnetic moments in SU(3) is being studied in an attempt to clarify the role of the resonant and nonresonant intermediate states in the continuum integral in the relevant current-algebra sum rule. The model-dependence of such vector-current sum rules is being studied, together with the question of consistency of vector and axial-vector sum rules for the Σ^+ moment. The aid is to clarify the theoretical situation, in view of forthcoming accurate measurements of $\mu(\Sigma^+)$. (Thomas Walsh)

Previous work[26] investigating nuclear forces arising via one-meson exchanges is being "phenomenologized" to find an effective static potential to simulate the momentum-dependent operator potential used in Ref. 26 to calculate scattering properties of the nucleon-nucleon system from 0- to 310-MeV incident laboratory energy, and bound-state properties of the deuteron and of nuclear matter. This potential will be more tractable for use in other nuclear physics calculations. The actual calculations are being done at UCSD in La Jolla on the CDC 3600 computer. (Lester Ingber, NSF Postdoctoral Fellow)

Techniques used to calculate the nucleon-nucleon momentum-dependent interaction mentioned above, and discussed in Ref. 26, can be used to calculate other low- and medium-energy elastic-scattering processes that are mediated by one-boson exchanges.[27] The two-particle Feynman graph, usually described by a function of energy and momentum transfer, is correctly used as a potential in Schrödinger's equation after the graph is described by a function of momentum and a radial parameter. (Lester Ingber, NSF Postdoctoral Fellow)

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24. Ivan Kramer, Resonances and Kinematical Peaks in Strong Interactions (Ph. D. thesis), University of California, Berkeley, February 1967.
25. F. Landis Markley, A Physical Interpretation of Static Model Parameters (Ph. D. thesis), UCRL-17502, April 1967.
26. Lester Ingber, Realistic Nuclear Forces, International Nucleon-Nucleon Conference, 1967, Gainsville, Florida, proceedings to be published in Bull. Am. Phys. Soc.
27. Lester Ingber, Correct Unitarization of Effective Potentials, UCRL-17497, April 1967, submitted to Phys. Rev. Letters.

II. NUCLEAR PHYSICS

After exploring many possible versions of a nuclear Thomas-Fermi equation, we have settled on a particularly simple form, suggested by the work of Seyler and Blanchard,[28] in which nuclear saturation is achieved by a velocity-dependent nucleon-nucleon interaction. We are now proceeding with detailed and comprehensive working out of this theory. This should provide a background to all those aspects of nuclear theory that do not depend explicitly on individual-particle structure. (W. D. Myers and W. J. Swiatecki)

A study of the families of equilibrium configurations of rotating, charged, or gravitating liquid masses has been taken up again. A major difficulty in establishing a continuous connection between the nuclear case of uniformly charged drops and the astronomical case of rotating gravitating masses appears to have been resolved. The question of the stability of the equilibrium configurations is being further examined as a result of a correspondence with S. Chandrasekhar. In particular the question of "ordinary" vs "secular" stability is being clarified. (W. J. Swiatecki)

We are working out the theory of the fission of a conducting charged drop in which the charge is distributed on the surface (rather than throughout the volume, as in the nuclear case). This is being done in connection with experiments on such drops which have been begun in the Chemistry Division. Together, the experiments and theory on the disintegration of conducting charged droplets by means of electrostatic forces will constitute a study of a phenomenon that appears to bear a sufficient similarity to the nuclear case to be able to throw light on nuclear fission. Advantages of a study of nuclear fission by means of such an analogue system are the automatic inclusion of dynamical effects, and the ease of investigating the effect of various parameters, such as the viscosity of the fluid.

The first stage of the theory is concerned with calculating the carrier energy for the fission of a conducting drop and the associated shapes of unstable equilibrium (the fission "saddle-point shapes"). This is being done using a theorem in electrostatics which makes it a trivial matter to calculate the electrostatic energy of conductors in the shape of any one of a family of equipotential surfaces generated by a system of point charges. Saddle shapes have been calculated for two point charges, but it is very likely that three or more charges will be needed before the associated equipotential surfaces provide a sufficiently close approximation to saddle-point shapes. (W. J. Swiatecki and C. F. Tsang)

28. R. G. Seyler and C. H. Blanchard, Phys. Rev. 124, 227 (1961); ibid 131, 355 (1963).

III. PLASMA PHYSICS, MANY-BODY PHYSICS, AND ATOMIC PHYSICS

Previous work[29] on the plasma kinetic equation is being extended in the direction of rigorous formulation of the equation. The condition for Markovian time development has been studied. The BBGKY hierarchy is being used to obtain an expression for the two-particle correlation function, including the effects of three-particle correlations. (A. N. Kaufman)

The stability of low-frequency drift waves in an inhomogeneous plasma has been studied in the small-Larmor-radius limit. In this limit, one can consider a situation in which the linear dimension along the magnetic field line is of the same order as that across the magnetic field line; an example is the magnetosphere. The Northrop-Teller kinetic equation was used instead of the Vlasov equation in the study. From this work a general stability criterion for a plasma sphere (where a dense cold plasma is present) was obtained. (C. S. Liu)

29. A. N. Kaufman, Phys. Rev. Letters 17, 1127 (1966).

An investigation of the effect of unstable transverse plasma waves on transport properties is in progress. (Norman Albright)

A transport equation applicable to dilute polyatomic gases is being sought. The nearly classical behavior of the molecules is being exploited to simplify a discussion of their internal (as well as translational) motion. Physical content is being sought in the Wigner function using as starting point the general scattering of wave packets. For structureless packets, a reasonable ensemble averaging of the Wigner function has led to the usual Boltzman equation; for internal motion, an appropriate generalization of the Wigner function has been found and its equation of change is being investigated. (Warren Wollman)

The theory of near-adiabatic scattering by atomic systems is being studied. The classical treatment of this problem by Landau and Zener gave an essential singularity in the scattering amplitude, whereas the method currently being used leads properly to branch-point singularities at thresholds. (K. M. Watson)

IV. ACCELERATOR STUDIES

A. Synchrotron Design

1. Extendible-Energy Synchrotrons

A study has been made on the feasibility of constructing synchrotrons for operation at one energy with provision for later conversion to a substantially higher energy by addition of new magnets and other components.[30] One may design guide-field configurations so that the original magnets remain at their old sites, requiring only minor realignments in the conversion. Orbit characteristics would not be changed significantly. Examples were designed for synchrotrons operating at 200 GeV initially and illustrating conversion capability to 300, 400, and 500 GeV. Cost estimates of the 300-GeV examples suggest that the additional initial cost is moderate, that the completed accelerator would compare favorably in total cost with a machine built in one stage for the higher energy, and that both stages would be comparable in performance to one-stage synchrotrons. (A. A. Garren with G. R. Lambertson, E. J. Lofgren, L. Smith, and other members of the Accelerator Study Group)

2. Long Straight Sections

Recent design improvements have made possible straight sections of sufficient length for extendible-energy synchrotrons without forcing a cell design with a higher value of the amplitude function β than would be chosen on other grounds. An especially effective arrangement for synchrotrons with the cell structure FOOFDOOD (where F and D represent radially focusing or defocusing magnets respectively) is to replace the OFDO portion of the cell with a long straight section array $\ell\ \ell_{F1}\ Q_{D2}\ L\ Q_{F2}\ Q_{D1}\ \ell$, where L is the long-drift space, ℓ are shorter drift lengths in the ends, and the Q's are quadrupoles. Values of L can be obtained at least twice as long as with the two-quadrupole Collins-type insertion. The longest L-values occur at $\ell \sim L/2$, and the phase advance is about 130 deg greater than in the replaced cell structure. If bending magnets are inserted in the ℓ sections, circumference is conserved and the momentum displacement greatly reduced. The theory for these matched insertions and cell-replacement structures has been extended to all combinations having an even number of lenses, reflection antisymmetry ($Q_F \longleftrightarrow Q_D$) about their midpoints, and arbitrary phase advance. The appropriate algorithms for these straight sections have been incorporated in the SYNCH computer code. (A. A. Garren)

3. Separated-Function 200-GeV Synchrotron

The availability of matched straight sections with greater length relative to β_{max} has stimulated the investigation of separated function lattices with very strong focusing as a possible improvement over the design-study machine. Thin-lens theory, reasonably valid for parameters of interest, shows that the length ℓ of a Q_F0Q_D0 cell that minimizes β_{max} is given by $\ell_0 = 2[C\rho(B_0/B')]^{\frac{1}{2}}$, where $C = \ell/2q$ is the quadrupole circumference ratio, q the length of each quadrupole, B' the quadrupole gradient, B_0 a reference field, and ρ the radius of curvature in that field. When ℓ is so chosen, β_{max} is $\sqrt{3}\,\ell_0$ and the phase advance is $2\pi/6$. These formulas may be inverted to determine the parameters required for a given β_{max}. Design of the new machine is based on the specification that β_{max} be about half as great as in the design-study, combined-function synchrotron. One obtains a cell length $\ell \sim 20$ m, which allows inclusion of two bending magnets of convenient length per cell. The betatron frequency ν is over twice as high and the displacement of off-momentum particles about 1/6 as great as in the reference machine. The long-straight sections are four-quadrupole replacements of half-cells with drift length the same as in the design-study machine. The total circumference is 5 to 10% greater and the quadrupoles increase the total iron length, but since the cross sectional area of the magnets would perhaps be about half that of the reference case, such a separated-function design may be more economical. Detailed design of such a machine and comparison with the combined-function reference case is in progress. (A. A. Garren)

B. Accelerator Design

The preceding Semiannual Report of this Division mentioned the resumption of studies concerning means for adjusting the closed orbit of an alternating-gradient synchrotron on the basis of data derived from pickup devices situated along the orbit.[31] During the period of the present report, this study has been confined to adjustments made by moving the 276 support points of the 200-GeV synchrotron described in the LRL

30. A. A. Garren, G. R. Lambertson, E. J. Lofgren, and L. Smith, Extendible Energy Synchrotrons, UCRL-17471, Feb. 21, 1967, Nucl. Instr. Methods, to be published.

31. Physics Semiannual Report, May through October 1966, UCRL-17282, January 1967, pp. 30 and 31.

Design-Study Report.[32] This computational investigation has concentrated on examination of the efficacy of the control system when it is applied to disturbances of various spatial extents that generate closed-orbit amplitudes of a standard magnitude sufficiently great to warrant correction. Realistic noise values were introduced into the 144 pickup signals, and additional errors were assumed to be present in the corrections themselves.

Preliminary examination of the results has indicated that the correction system can effect a substantial reduction, to acceptable levels, of closed-orbit errors arising from misalignment of the accelerator supports. It should be possible to identify localized misalignments of this type by recognition of the simple, essentially sinusoidal, character of the closed-orbit displacement outside the disturbed region. The computational program has been adapted to recognize such localized misalignments and to recommend corrections that are confined to the neighborhood of the disturbed region. These localized corrections--that in practice would require less effort to introduce--have been found to provide in such cases an alternative and attractive means of obtaining an efficient correction. Plans are presently being made to extend the computational investigation to include the use of magnetic orbit deflectors, for the correction of closed-orbit distortions that arise from either positional misalignments or from magnetic errors in the accelerator structure. (J. E. Braley, G. R. Lambertson, and L. J. Laslett)

A computational program has been initiated to investigate the long-time stability of particles whose motion in one transverse degree of freedom can be characterized by a nonlinear (area-preserving) algebraic transformation. This work is being performed in double-precision arithmetic with the LRL CDC-6600 computer, using a program designed to minimize both the computational time per iteration and the truncation errors of the numerical work. In parallel with the computational investigation, some analysis has been attempted of the numerical errors necessarily present in such work, in order that the cumulative effect of small drifts and fluctuations in the numerical work will not be confused with intrinsic characteristics of the algebraic transformation. In relation to accelerator technology, the stability of iterates of a nonlinear transformation may be of particular interest with respect to the survival of particles in a storage-ring facility. (L. Jackson Laslett)

The preceding Semiannual Report described the influence that clearing electrodes and their terminations can have on the transverse resistive-wall instability of a coasting beam in high-intensity particle accelerators or storage-ring devices.[33] An analysis of this effect for a specific electrode configuration was reported at the 1966 International Symposium on Electron and Positron Storage Rings (Saclay, 26-30 September), and this report has now appeared in the Proceedings of the Symposium.[34] (L. Jackson Laslett)

Distribution functions for a beam of particles in an accelerator have been studied. Previous work[35] employed a four-dimensional distribution function which yields linear space-charge forces in real two-dimensional space. Efforts to extend this work to three degrees of freedom have failed, and recently we have proved that no six-dimensional distribution function can give linear space-charge forces. Presently we are investigating the stability of one- and two-dimensional distribution functions to small perturbations. (Frank Sacherer and Lloyd Smith)

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32. 200-BeV Accelerator Design Study, Vols. I and II, UCRL-16000, June 1965.

33. Physics Semiannual Report, May through October 1966, UCRL-17282, January 1967, pp. 28 and 29.

34. L. Jackson Laslett, Concerning the Self Fields of a Beam Oscillating Transversely in the Presence of Clearing-Electrode Plates, in Proceedings of the 1966 International Symposium on Electron and Positron Storage Rings (Presses Universitaires de France, Paris, 1967), paper IV-5, pp. 1-8.

35. Frank Sacherer, The Behavior of Intense Charged Beams in the Presence of Gradient Errors, UCID-10189, June 1966, unpublished.

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Charles B. Chiu and Jerome Finkelstein, Suggestive Features in πN Charge-Exchange Polarization Associated with Regge Cuts, UCRL-17318, January 10, 1967; Nuovo Cimento 48A, 820 (1967).

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William Rarita, Robert J. Riddell, Jr., Charles B. Chiu, and Robert J. N. Phillips, Regge-Pole Model for πp, pp, and $\bar{p}p$ Scattering, UCRL-17444 Abstract, March 13, 1967; APS Meeting, Washington, D. C.

Henry P. Stapp, Analyticity Properties of Helicity Amplitude, UCRL-17429, March 20, 1967; to be published in Phys. Rev.

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MATHEMATICS AND COMPUTING SERVICES GROUP

Kent K. Curtis in charge

During the period of this report (November 1966 through April 1967), members of the Mathematics and Computing Services Group performed the following tasks for the Laboratory research groups.

Applications Programming

Powell-Birge Group

The COBWEB[1] project for the control of bubble chamber film measuring machines using an IBM 7044 computer is being debugged. A diagnostic program was written to aid the engineers in debugging the COBWEB hardware. The hardware is planned to be operational during May 1967. The IBM 7044 measuring procedure program is designed, 95% coded, and 50% debugged. This program is expected to become operational sometime during June, 1967. In addition, work is proceeding on a subprogram within COBWEB to enable scanners to input scan information to the IBM 7044 via a teletype.

The CDC 6600 editing program, EDIT, is being written to convert COBWEB output tapes to various formats. Initially, these formats are identical to those now used by the measuring machines in order to maintain compatibility with other production systems. (Bert Albrecht and Myron Myers)

A Powell-Birge bookkeeping program, LIBRO, was written, debugged, and is in production. This event-accounting program is very similar to BOOKIE,[2] but is much improved with respect to the operations it can perform. Input to the program consists of scan-card images, Event Accounting tapes (from the Data Handling Group), and Fortran Fair tapes. In addition to keeping statistics associated with the normal bubble chamber events processed, LIBRO also maintains statistics on "identify only" events. LIBRO also can identify, by printing and (or) generating scan-card images, those events that require remeasurement. (Bert Albrecht for Powell-Birge)

1. Physics Division Semiannual Report (hereafter abbreviated PDSR, UCRL-17282, October 1966, p. 27; E. P. Binnall and M. H. Myers COBWEB: IBM 7044/On-Line Bubble Chamber Film Measuring Machines, UCRL-17136, September 1966; presented at AEC Information Meeting, Washington, D. C., September 28, 1966.
2. PDSR, UCRL-16863, May 1966, p. 32.

Various programs relevant to the Powell/Birge data-reduction effort were modified to improve efficiency and converted to the CDC 6600. The Powell-Birge data-reduction computer operations system was studied and improvements implemented to insure more through-put as well as better communication with, and more efficient use of the expediters. (John Visser, Bert Albrecht, Esther Coleman, and Myron Myers)

A package of CDC 6600 CRT display subroutines, written to manipulate data in a logical record format and output various displays on the Cal-Comp or CRT, have been modified to take advantage of the on-line CRT capability. All display work thus far has involved only histograms and selection criteria (FILTER)[3] in an effort to use as little memory space as possible. The user can view his histograms at the VISTA console, change scales, combine histograms, and save selected ones on the microfilm recorder. The user can also change the control cards that define the histograms and selection criteria, and then reprocess the input data. (Ester Coleman, Bert Albrecht, and Myron Myers)

The kinematics routine BISE[4] was revised and improved. Preliminary analyses of the program results revealed that further fits could be made. These were obtained by allowing more than the usual number of iterations for those events which appeared to be converging slowly. The requirement of a decrease in the sum of the constraints was relaxed on the first iteration, resulting in still more fits. Other changes resulted in a 20% saving in machine time.

From the original group of 7000 events, those which failed to fit any hypothesis during the first running of BISE were rerun with the revised program. About 23% of the reruns now fitted and the results from both runs were combined. The complete results agreed with known cross sections; further analysis is in progress.

A detailed description of the techniques used in BISE has been completed and is being made into a UCRL report.

The question of the suitability of existing kinematics routines for events taking place at

3. D. V. Armstrong, FILTER, Physics Note 141, February 5, 1966.
4. PDSR, UCRL-16511, November 1966, p. 26.

energies of 100 GeV/c and greater has been looked into by Plano and others. Plano reported that double-precision arithmetic was necessary for proper convergence on both 36 bit and 60 bit computers. A program HIGH has been written in FORTRAN to generate 100 GeV/c events of the types constrained by BISE, to see if the somewhat different techniques using single-precision arithmetic will give convergence. HIGH is now being debugged. (Harold Hanerfeld for Powell-Birge Group)

Trilling-Goldhaber Group

Work is being done in the area of converting to a new data-analysis system. The objectives have been to reduce the number of steps required to completely process an event, to keep the time required to a minimum, to reduce the number of tapes that must be kept, and to utilize existing programs as much as possible. The bulk of the programs run on the CDC 6600, with conversion in progress for those that still run on the IBM 7044 or 7094. Older experiments that were started on IBM equipment are being completed on that equipment. The tape libraries are being examined and subsequently reduced in size and then placed in the Mathematics and Computing tape library or in long-term storage.

Current experiments being processed with the new system are K^+p at 9 GeV/c in the BNL 80-in. bubble chamber and π^+p at 3.6 GeV/c in the LRL 72-in. chamber. Upwards of 50 000 events have been processed in the last six months. (Jose Alvarez, Derik Armstrong, Emmett Burns, Dan Lamb, and Jim Miller)

A new least-squares vertex subroutine was written for TGIF.[5] Extensive testing was done to bring the vertex problem to a good capability of resolution in TGIF. That portion of the program dealing with two tracks in a road logic was refined further and additions were made for the two-point track mode. General maintenance and updating for new experiments was also done. (Jim Miller)

SIOUX[6] has been modified from the Alvarez version to meet the needs of the Trilling/Goldhaber Group. Event types and experiment-dependent constants have been added for two new experiments. A project to modify TVGP[7] to increase the number of passing events has been started. Additional tests have also been added to prevent arithmetic-error stops. (Jose Alvarez and Emmett Burns)

A series of routines has been written to be used with the ARROW[8] system. The routines select and calculate the quantities desired by the physicists. Additional routines are being written for the newer experiments. (Dan Lamb)

A new set of routines called EXAM have been written to allow the user access to the express mode. These routines operate from an ARROW output tape that contains a minimum amount of data for each event and calculates masses, angles, etc. (Derik Armstrong)

In the PANAL,[9] PACKAGE,[10] and EPC areas, work has been done in researching, explaining, and advising the users on how the various geometry, kinematics and translation programs work. (Jim Miller)

A new program called FOGGY enables the user to extract in various forms scanning and measuring data from FSD event-accounting data tapes. The basic routine was obtained from the Segre-Chamberlain Group. A good portion of it was recoded to improve efficiency.

FLIB, a library program for Franckenstein data cards, is nearing completion. It will enable the user to store measurement data and extract it under the control of filter or scan cards. (Derik Armstrong, Jose Alvarez)

A new program called PHONY is in the final debugging stage. It was built from the two existing programs--FAKE (UCRL-10335 and Trilling-Goldhaber notes) and SIMULATE (Alvarez Programming Note 129)--to generate vertices, tracks, and pseudo-measured points. These programs were modified to communicate with each other and to prepare an input tape for SIOUX. (Emmett Burns)

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5. A. D. Johnson, Preliminary Trilling-Goldhaber Input Format (TGIF), Alvarez Memo No. P-118, March 12, 1965 (not for distribution outside of LRL).
6. PDSR, UCRL-16511, November 1965, p. 25.
7. A. D. Johnson and T. B. Day, Three-View Geometry Program, Alvarez Programming Date P-117, June 8, 1965; PDSR, UCRL-16511, November 1965.
8. Orin Dahl, ARROW, Alvarez Programming Note P-124 (preliminary), August 3, 1965; PDSR, UCRL-17282, January 1967, p. 28.
9. M. Hutchinson, PANAL, Alvarez Programming Note 358 Rev., February 1, 1963.
10. Barrie Pardoe, PACKAGE, Alvarez Programming Notes P-27, January 30, 1963, and P-40, April 22, 1963.

Spark Chambers

The program LKGLOP for the Kaufman cyclotron experiment π^- + He interaction was completed. In its final form the program punches the processed events on cards, and the experimenter selects the events to be used with the card-sorting equipment. This approach was deemed necessary because it is not known where general cutoffs should be applied, but selection by hand could be used. (Tony Schaeffer for Leon Kaufman)

A series of codes (STND, SMERGE, RCNTRK) has been developed for reading output from the SASS-Vidicon system and reconstructing spatial coordinates for input to a momentum-analysis program.

The sequence of steps is as follows: Standardized reference tables are created from carefully prepared photographs of the spark chamber's grid marks and fiducials. Subsequent reference measurements from a given run are then standardized from these tables and the event data are adjusted accordingly. The output from these transformations is then fed to a reconstruction program which, utilizing a program (SCRUBL) written by Al Clark, pairs the event data of each view and computes the spatial coordinates and their variances. Linkage to a modified version of TRACK has been successful. (Leo Vardas for Al Clark)

VISTST, a set of subroutines using the 250 Vista system, has been written to allow on-line monitoring of the basic track-recognition programs developed for the Crowe Bevatron experiment. It is now possible for the user to observe the working of the track-recognition programs and quickly discover needed adjustments and modifications. It is also possible by using the light pen to correct the program at any stage and thus insure error-free scanning.

Input to the basic track-recognition programs is in the form of two tables of spark coordinates, one for each of two 90-deg stereo views of the chamber. Consequently, it is possible to adapt the programs to process data from different experiments and different measuring machines with considerable ease. (Les Wilson for Crowe Group)

Accelerator and Magnet Design

1. Magnet design. Program LINDA[11] has been 80% completed. (Tom Clements for Charles Dols)

Program TRIM[12] has been operational for some time with both the rectangular and cylindrical versions being in heavy production use by the Lofgren and Chamberlain Physics Groups, Inorganic Materials, and the AGS study groups. Substantial monetary savings are being realized in the magnet design because this program allows the user to design "paper" magnets to conform with the desired specifications without building prototypes. In actual cases, the calculated fields have been within 1% of measured fields. (J. Colonias, B. Burkhart, R. Healey, and R. Ahlstrand)

An experimental program FIELD[13] has been written to investigate the possibility of utilizing the graphic-display consoles of the 6600 to calculate magnetic fields. This program will allow the user to draw the magnet geometry on the CRT screen, perform modifications or alterations on magnet geometry, and display the resulting flux distribution and pertinent curves revealing the quality of the field throughout the magnet. This program shows great potentialities and presently is being adapted for production use. (J. Colonias)

Program TAMI[14] is a general purpose code for the solution of the three-dimensional magnetostatic problem containing magnetic materials. The program has been written and is being debugged. (Steven Sackett)

2. Orbit studies. The preliminary study on orbit codes and beam-transport design programs[15] has been started in order to establish a set of programs to meet the needs of the general user at this laboratory.

The findings and recommendations of this study are summarized in a report to be published soon. As a first step, program

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11. PDSR, UCRL-16863, May 15, 1966, p. 31.

12. J. S. Colonias, and J. Dorst, Magnet Design Applications of the Magnetostatic Program Called TRIM, UCRL-16382, September 1, 1965. September 1964; J. S. Colonias, Computer Calculation of Two-Dimensional Magnetic Fields, UCRL-17319, January 3, 1967.

13. J. S. Colonias, Calculation of Two Dimensional Magnetic Fields by Digital Display Techniques, UCRL-17340, April 28, 1967.

14. Steven Sackett, A Computer Code (TAMI) for Magnetic Fields in 3-D Space with Magnetic Materials Present, ENA66-371, January 3, 1967.

15. J. S. Colonias et al., Computer Programs for Cyclotron, Synchrotron, and Beam-Transport Design, (Internal Report, available from Mathematics and Computing Library, Sept. 1966).

CYDE[16] has been completed and is operational for the IBM 7094 computer system.

A beam-transport program SOTRM is under development to calculate the first- and second-order transfer matrices associated with any magnetic element for which a field configuration can be furnished. In the final form this program will be able to trace a reference particle in any direction through a given magnetic field and will furnish the associated transfer matrices. (Elon Close for the 88-Inch Cyclotron Group)

Program ELOSS[17] was modified to include the calculation of the momentum-loss probability function, and various programs are under development to aid in improving the performance of the 184-inch cyclotron by studying the effects of modifying the field and the rate of frequency modulation. (Vic Brady for D. Clark)

A Fortran version of program TRANSPORT[18] has been modified and converted to the CDC 6600. The feasibility of designing beam-transport systems on the 6600 computer with on-line user interaction via the CRT display console with a light pen has been established, and a program utilizing this feature has been started. (J. Colonias)

A set of programs TIGER has been developed to study corrections to be applied to the support-pile structure of an accelerator to maintain correct alignment on the basis of beam pickup information. Closed-orbit displacements due to magnet errors are also being investigated. A program CRAWL to study the long-range stability of nonlinear algebraic transformations that could arise in storage-ring problems is under development. (B. Levine for J. Laslett)

3. Linear-accelerator design. The code, PYRMI, is a modification of the linear-accelerator design code, PARMILA. It provides these additional features: omission or arbitrary assignment of strength and polarity for any of the cell quadrupoles, and insertion of more-complex magnet systems consisting of quadrupoles and bending magnets with wedge angles in intertank spaces. (Jonathan Young for Ed Hubbard)

Linear programming has been used to determine parameters in order to maximize drift length in straight sections in connection with the 200 to 400 GeV accelerator design. The linear programming code, LP-90, was used on the 7094. (Jonathan Young for Al Garren)

4. Special Projects. Program FLUX is a special program developed to aid in the construction of a functional representation of radiation data associated with the CERN Proton Synchrotron. Programs of this type are useful in connection with shielding studies for the proposed 200-BeV proton synchrotron.

Program NONAME has been written to investigate transmission-line problems associated with variable magnet power supplies.

The programs TRIM and PIZZA[19] have been combined to provide a general-purpose program that allows the user to determine the pole-face geometry of a magnet when the desired performance is given. This program is very effective and provides a significant contribution to the design of magnets.

A new version of TRIM has also been written which is five times faster than the previous version. This program includes new edit routines to improve the quality of the computed fields and gradients. (Jim Spoerl for the OMNITRON Group)

A recent experiment has been performed on the linear accelerator which is used to inject protons into the Bevatron. Several 6600 Fortran IV programs, including BALL and TBALL, have been written to study the accelerating field, E(Z), and other related parameters such as the transit-time factor of each cell, measured in the standing-wave cavity. The accelerating field was determined by measuring the change in resonant frequency caused by a small perturbing sphere on the axis of the cavity. Correlations are being found between the 20 wall probes [HBAR(Z)] and both the average axial field [EBAR(Z)] and the tuner positions [TP(Z)]. By observing HBAR(Z) and TP(Z), it will be possible to adjust EBAR(Z), which cannot be measured while the accelerator is running. This experiment should lead to a more accurate prediction of the linear-accelerator's operation. (E. Williams for Robert Allison et al.)

Further refinements of the injector control system using the PDP-5 have been made, especially in the area of operator-communications.

16. Elon Close, A collection of FORTRAN II Cyclotron Development Codes for Use on the IBM 7094, UCID 2869, January 1967.
17. PDSR, UCRL-17282, October 1966, p. 29.
18. PDSR, UCRL-16411, November 10, 1965, p. 24.
19. Klaus Halback, A Program for Inversion of System Analysis and Its Application to the Design of Magnets, UCRL-17436, March 1967.
20. PDSR, UCRL-16511, November 1965, p. 28.

During the Bevatron shutdown, the PDP-5 system has been used to control the experiment to determine the electric field in the linac and the effect of the tuners on the field. A program was written to control the equipment and put the data on tape for processing on the CDC 6600. (Bob Belshe for B. Allison)

Nuclear Chemistry

Two Gaussian fitting programs were written to resolve prompt K–x-ray spectra from Cf^{252} fission fragments. Program PAIRSIG fitted Gaussians to quadrupole x-ray calibration spectra in order to obtain information on peak position, width, and area ratios of known decaying isotopes. This information was used in program SEVER to isolate the energy and amount of the 23 isotopes that formed the K–x-ray spectra. (Claudette Rugge for Rand Watson)

In the search for fine structure within the analysis of angular distributions of fission fragments, program P-FIT[20] was reparameterized to eliminate the error introduction by normalizing the data to a Legendre polynominal fit at 90 deg. The input and output sections of the modified program PU-FIT were also refined. (Claudette Rugge for Luciano Moretto)

In the study of interactions between extranuclear magnetic or electric fields, the program XCOS1 was written. The program fits time-differential measurements observed as periodic modulation of decay of the intermediate nuclear level. The program was extended to preface this by a fit to a possible exponential deformation of a decaying daughter during the measurement time. (Claudette Rugge for E. Matthias and B. Treytl)

The program EDELS was written to determine from experimental data the crystal field splitting of a J-manifold in cubic symmetry. Library routines were employed to find eigenvalues, do curve fits, and make graphs. (Ruth Hinkins for Norman Edelstein)

Work was begun on obtaining the numerical solution of the transient diffusion in a composite slab. The problem is being solved by a truncated eigenfunction-series technique.[21] (Paul Concus and Donald Olander)

The program SCATER 2 was changed from a vibrational-model calculation to a rotational-model calculation. SCATER 2 now has the addition of using large numbers of partial waves necessary for heavier elements, and it takes into account the K = 2 bands. All the linearly independent solutions of the second-order partial differential equations were solved simultaneously rather than sequentially as in the previous program. This resulted in a large saving in time at a cost of increased memory space. The number of coupled channels was expanded to 36.

It was concluded that higher-order interaction terms in the nuclear potential were important for angular-momentum transfers of four or more. The program RADIAL was written to display on the Cal-Comp the interaction terms in the nuclear potential.

Modifications were made to the program CROSS 2 and CROSS 1 for increased speed and for different Cal-Comp formats.

The series of programs MICRO,[22] DIFFER,[23] and CROSS[24] were modified for increased speed and so that 41 coupled channels could be handled. (Noel Brown for Norman Glendenning)

The PDP-7 assembler write-up and users manual is now available from the Mathematics and Computing Library. New instructions have been added to the relocatable version of the assembler, which is now available on the data cell.

The PDP-7 ADC control program TWIST is complete. It is designed as a main framework to which variable "black boxes" can be attached to suit the individual user. The main framework and the individual "box" routines can be stored separately on DEC tape, and various initialization, run-time processing, and post-processing routines can be "plugged in" at the user's discretion. At present one general initialization routine and several run-time and post-processing routines are available. Others will be added as required by the users.

A PDP-7 Cal-Comp package to allow a user to create graphical display on the Cal-Comp plotter is near completion. Also, a program to plot Cal-Comp tapes generated by the CDC 6600 has been started. (Penny Collom for Nuclear Chemistry)

21. Paul Concus, On the Numerical Solution of a Diffusion Equation, UCID-2912, March 7, 1967.

22. PDSR, UCRL-16099, November 1964, p. 30; PDSR, UCRL-16511, p. 29, November 1965.
23. PDSR, UCRL-16099, November 1964, p. 30.
24. PDSR, UCRL-16099, November 1964, p. 30.

Work has begun on a PDP-8 program (ART) for multiple-parameter pulse-height analysis of on-line and off-line data and display of the information via a CRT. An integral part of the system is a disk store. The basic routines for buffering data from the on-line ADC to the disk have been completed. Work is now proceeding on routines to analyze the data and display it. (Dave Jenson, Bob Powell for Art Pastkanyer)

Biomedical Applications

Results obtained for the age distributions of stochastically dividing populations[25] imply that the proliferative control of a statistically stable population of stem cells cannot be based solely on an exogenous demand for differentiated cells, but must be based in part on the size or rate of growth of the population itself. This conclusion significantly limits the kinds of stem-cell control possible. (G. C. Nooney)

A processing system for medical data relating to radiation treatment for diabetes mellitus has now been extended. The Tulane University program TIPS[26] has been used to build a computer-based data file, to correct and edit the data, to obtain selective printed output, and to prepare magnetic tapes for use by another program. This second program (MED) can generate plots and histograms which are displayed on a VISTA CRT or drawn on a Cal-Comp plotter. The design of clinical trials to investigate the efficacy of the radiation treatment has also been studied. (W. Hogan, T. Mahan, M. Horovitz)

Calculation from experimental data of the iron-uptake rate of erythrons as a function of erythron age has now become routine with the use of NMOD. Results for several normal subjects have made doubtful the validity of models of iron kinetics having a significant iron compartment between plasma and heme and have brought into question the accuracy of most available experimental data. (G. C. Nooney and T. Mahan) Other work on iron kinetics included a program to determine the transfer function of Fe^{59} from plasma to red cells and a program for the analysis of external monitoring data. (K. Wiley)

Several programs were written and used to fit various functions to data on the time course of evolution of $C^{14}O$ in the breath of animals. (M. Horovitz) Work has continued on the program GASP, which fits a model to data from a $C^{14}O_2$ breath analyser. (K. Wiley)

A Monte Carlo simulation was used to obtain confidence intervals for average weight in different comparison groups of mice with various radiation histories. (W. Hogan)

Program TELLY was written to find approximate solutions of an integral equation relating measured activity to neutron flux and cross sections. The user can modify the flux function by drawing it on a CRT with a light pen until a satisfactory fit between the corresponding integrals and the data has been obtained. (M. Simmons)

Program BRAGG[27] was completed and used to compute dosage-versus-distance curves for various cases. Results have been reported. (G. Litton)

Miscellaneous

Substantial progress has been made in the development of the program FINDME for the analysis of emission spectra. Applications of this program exist in many areas, including the study of stars and the measurements of the energy levels of diatomic molecules. The immediate use of the program will be in the analysis of emission spectra obtained from compounds activated in electrodeless discharge tubes or in low-pressure arcs.

The program operates primarily by taking a large number of spectral lines and sorting them into subsets, each of which is assumed to have a specific mathematical representation. Due to the large number of spectral lines which may be contained in a given set, and due to the inherently large computer time associated with a search routine of this nature, a good deal of work has gone into developing methods for minimizing computing time. This has centered in part around working out data-storage schemes peculiar to the problem.

A large number of options have been included in the program. These are to allow as much flexibility as possible in setting the criteria necessary to subdivide a spectrum into its components.

A flexible input routine has been attached to the program. This allows input cards to be arranged in random order, with only those cards being supplied which are necessary to the operation of a given problem. (Gerry Litton for John Phillips)

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25. Grove C. Nooney, Age Distribitions of Stochastically Dividing Populations, UCRL-17356, January 27, 1967.
26. Richard D. Yoder et al., Tulane Information Processing System, Version II. Tulane University School of Medicine, 1966.
27. PDSR, UCRL-17282, October 1966, p. 30.

The program CHRYS was written to compute and plot the stereographic projection of all the molecules of a crystal that are located in a shell of given radius and thickness. This was done for a perfect crystal and for several distorted crystals. (Ruth Hinkins for Pierre Petroff)

The program OMNI was written to compute one of the components of the magnetic field intensity in ferrite. Permeability is determined by fitting experimental data. By using this permeability and by varying parameters for the high-frequency Omnitron resonator, plots are produced involving frequency, current, radius, and length.

The program CHAT was written to find inductance from experimental voltage and current data. This calculated inductance is used with bias currents determined by another program to produce new voltage curves on the Cal-Comp plotter.

Preliminary work has been done on the program DERIEN which is to display the solutions of a system of differential equations on the CRT as several parameters are varied. (Ruth Hinkins for William Gagnon)

PUZZLE,[28] a program that aids in printed circuit design, is presently being used for production. It has proved of value in reducing both the time and cost of producing printed-circuit boards. General maintenance work to allow for a more sophisticated plotting procedure, the addition of error tests on data to provide as complete a layout as possible from a given run, and the writing of the initial sections and flowcharts necessary for accurate documentation of the program have been completed. (Deanna Wilber for Ron Zane)

Work was finished on rewriting a Chamberlain Group program called SCOFF. This program is written for the PDP-5, and is used for on-line data collection and preliminary analysis in a particle scattering experiment. The basic program is completed and operational, and a comprehensive description of the program is near completion. (Dave Jenson for Tony Parsons)

A program, COSTAL, was written for the CDC 6600 to tabulate the current purchase-order commitments of the Berkeley Laboratory. Using the estimated delivery date of each item as a criterion to determine when payments fall due, the commitments are projected eight weeks ahead from the date of the run and tallied separately under departments and sub-departments. Each week the commitment record is updated with information on new purchase orders and disbursements on existing purchase orders. (Marjory Simmons for B. Kinckley)

28. PDSR, UCRL-16511, November 1965, p.30.

A set of computer programs (GROUP, CORRECT, RATEI, REPORT, STATUS,RATEII BASIS) have been written to forecast average payroll information by payroll group on a full-time equivalent (FTE) basis and to prepare appropriate reports. Historic information used includes selected information on individual employees, monthly gross-earned reports by payroll groups, and monthly FTE basis reports by payroll groups. All of these programs are in use except RATE II, which is being debugged. (Bob Healey for John Stark)

STAP3, the new version of the program used to record and maintain LRL inventory, is in the final debugging stages. Major revision of the tape-handling procedure has taken place, and a minimum of external tapes are being used. A full-scale test case is yielding most reports in a satisfactory manner. Documentation on STAP3 has been started and is near completion. (Deanna Wilber for Tom Hitchcock)

Work has begun on the program POFO to produce the various reports required for inventory control and purchasing. POFO features a format-free input that allows a user to specify in English-like statements what information from a master file will be included in the report and what summary operations will be performed on that information. Because the number of reports is specified by the user, storage is allocated dynamically to optimize the use of storage and to permit the master file to be read only once. (Dave Jenson for Tom Hitchcock)

Several programs have been written for the Technical Information Division to process and search information from Nuclear Science Abstracts (NSA). TIDE I and TIDE II (see UCID-2828) have been modified to run more efficiently, (e.g., TIDE II has been speeded up by a factor of 10). Also, TIDE I makes a tape with the accumulated frequency of keyword selectors found in the documents of NSA. This information will aid the profiler in forming "better" search questions.

Program INDEX, now being debugged, will provide the libraries at LRL with a list of the documents on the NSA tape along with an author index to those documents. (R. N. Healey for Ray Wakerling and Gloria Smith)

29. K. C. Knowlton, Commun. ACM 9, 1616 (1966).

A preliminary list processor, L66, based on an abbreviated version of Knowlton's L6,[29] has been completed. This processor will enable bootstrapping to a more powerful and flexible compiler that will operate quite efficiently. One underlying goal has been to provide complete compatibility with FORTRAN IV and ASCENT. The second-generation compiler should prove extremely useful both to FORTRAN users who wish efficient bit and character manipulation and to users who need to generate and manipulate list structures such as those that occur in inventory studies and graphic displays applications. (Leo Vardas and Dave Jenson)

A program LION to help assess track-following techniques used on bubble-chamber data obtained from photo-scanning devices is being written in FORTRAN. Several of the necessary subroutines have been written and debugged. (Harold Hanerfeld)

Systems Programming

PDP 5/8

Diagnostic and system programs to utilize the M6 data disc on the PDP-5 and PDP-8 have been written and checked out. The PDP-5 disc also is used to drive a CRT display. A program was written to plot data and alphanumeric characters with this display system. (Bob Belshe)

DDP-24

The film-scanning programs have required constant revision to solve scanning problems that arose at experiment time; a program was written to edit and skelm the output tapes from the scanning programs. (Don Zurlinden)

6411

The interim 6411 system, which has been in use for a year, was replaced by ASOP1 (Attached Support Operations, Version 1). In addition to the 1401/1460-type operations provided by the interim system, ASOP1 provides on-line support of the 6600 and a modest remote console facility. Work in progress includes expansion of the system to handle two 6600's and the ability to "attach" a teletype to a 250 console, providing more flexible I/O for the user of the 250. (Sam Penny, Jerry Borges, Bob Fink, Judy Glasner, Walt Hutchinson, and Doug Brainard).

A hardware design error in the 210 consoles, causing excessive flicker, was detected and corrected. (Jerry Knight)

6600

Systems improvements and extensions included:
(1) The ability to run all system I/O functions at a single control point;
(2) Making both disks available for use by the system;
(3) Incorporation of the SCOPE 2.0 system;
(4) Extensive modification of the operators' console displays;
(5) Improving job scheduling. (Bob Tracy, CDC, and Jerry Knight)

Some extensions for the compiler were provided, and the error-tracing facilities of SCOPE 2.0 were made available to users of the standard BKY system. (Joyce Johnston, CDC) Limited access was provided to the IBM 2321 Data-Cell Drive. (Bob Fink)

An investigation was begun into methods of evaluating system performance. (Charles Symons, CERN, Mike Long, and Dave Stevens)

Implementation of an improved method of assigning disk tracks was begun. (Jerry Knight)

Mass-Storage System

The definition of the external specifications for a comprehensive mass-storage system (involving the IBM 2321 data-cell drive, a CDC 854 disk pack, and the IBM photo-digital chip store) was nearly completed. (Margret Alston Garnjost, Sam Penny, Bob Fink, and Dave Moss)

PDP-5 Link

The (hardware and software) design of an intermittent on-line link between the 6600 and a PDP-5 at the Bevatron (or other remote location) was begun. This link would permit nearly on-line processing by the 6600 of sample data to facilitate control of experiments without significantly degrading total 6600 performance. (Sypko Andreae, Doug Brainard, and Tony Schaeffer)

Mathematical Research

A revised version of a report entitled "Numerical Solution of the Minimal Surface Equation" (UCRL-16927 Rev.) was prepared to make it acceptable for publication in Mathematics of Computation (July 1967). (Paul Concus)

Work continued on extending the method of the above report to numerically solve the equation of a surface with mean curvature that varies linearly with height, subject to normal derivative boundary conditions. This equation is the one that determines the equilibrium free surface in a container of a fluid subject to surface and gravitational forces. The solution has been obtained for a container with circular cross section and for a few values of the parameters for a container with square cross section. Work was begun on the characterization of the parameter domains for which solutions exist for different cross sections. (Paul Concus and Marjory Simmons)

A method was formulated for numerically solving the magnetostatic field equation in two dimensions that would allow inclusion of hysteresis effects. Two-dimensional hysteresis has not, in general, been physically formulated; physically reasonable models were postulated in the mathematical formulation of the method. (Paul Concus and Alan Winslow)

A doctoral thesis "Invariant Surfaces of Ordinary Differential Equations with and without Time Lag" has been completed.[30] (Tony Schaeffer)

A technique has been developed for approximating a discrete function, $(x_i, y_i)\ i = 1, I$ by a linear combination of a specified number, J, of functions, f^j, of the forms

$$\exp(a_j x),$$
$$\sin(b_j x),$$
$$\cos(b_j x),$$
$$\exp(a_j x)\sin(b_j x),$$
or
$$\exp(a_j x)\cos(b_j x)\ .$$

The technique involves approximating derivatives for the function, finding the linear differential equation with constant coefficients satisfied by these derivatives, finding the general solutions (the f^j above) and finally finding the coefficients for the linear combination of the f^j.

Approximation methods using variation of parameters would require $I \geq 2J$, whereas the technique described requires only $I \geq J + 1$.

30. Anthony J. Schaeffer, Ph. D. thesis, UCRL-17525, April 1967.

The code, EYGFYT, has been written to apply the technique to small problems ($I \leq 11$, $J \leq 10$) and has given satisfactory results. Derivative values were first obtained using a polynomial approximation. A first trial set of f^j and c_j was computed for these. Next these f^j and c_j together with errors were used to compute a new set of derivative values. A next set of f^j and c_j was then computed. Although the iteration could be continued, in all cases tried, the second set was a good approximation. (Jonathan Young)

Computer Operations

In December of 1966, the CDC 6411 and CDC 6600 computer systems were moved to Room 1275, Building 50B. An IBM 1460 computer was returned to IBM in January of 1967. In February of 1967, the 7044 computer was moved from Building 70A to Building 50A, Room 1156.

During the month of January, the keypunch, library, and ready-room facilities were moved from Building 50A to Building 50B.

A magnetic-tape library was established in Building 50B and has been in operation since March 1967. Access to this Library from the main computer room is via a single-floor lift.

In March and April as occupation of Building 50B was completed utilization of a 6-floor lift as a means of submitting jobs to the CDC 6600 and of returning such work to the user was started.

Vista consoles were installed on the first, second, third, and fifth floors of Building 50B for utilization as remote, interactive, graphical, input-output devices.

Site plans were completed and work was started on site preparation for a second CDC 6600 to be delivered in July 1967. (James Baker, Paul Rhodes, and Marvin Atchley)

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PHYSICS RESEARCH

Kenneth M. Crowe in charge

NEUTRAL BEAM AT SLAC

Kenneth M. Crowe, David Dorfan, Donald Miller, M. M. Schwartz, Michael Paciotti, and Don Wajoiski

A collaboration has been initiated with members of Stanford Group G to measure the charge asymmetry in the leptonic decay modes

$$R = \frac{+\ (K_1^0 \rightarrow \pi^- + \mu^+ + \nu)}{-\ (K_1^0 \rightarrow \pi^+ + \mu^- + \nu)}$$

of the long-lived component of the neutral K meson. The experimental setup consists of counters, spark chambers, an analyzing magnet to determine the sign of the muon, and a large range chamber to establish the muon's identity by lack of interaction.

The experiment is now in progress, and a limited amount of data has been taken. The sign of the muon is decided by a counter array; at the same time, we take sample pictures at 10% of the event rate to correct for small effects such as wrong sign decision, interactions, etc. All relevant accidental rates are scaled.

We will soon start a thorough experimental study of systematic effects in the entire system. Once these are understood, statistics will be collected to the limit imposed by the systematic errors, or to the limit of available running time. We hope for an error in R of less than 0.3%. With this experiment we can probably check the consistency of R within the present theoretical framework and then possibly exclude one of the two proposed solutions.

ANALYSIS OF K^+ DECAY AT REST

Michael Zeller

An experiment performed in the early part of 1965 to measure the various parameters in the leptonic decays of the K^+ meson is presently in the final stages of analysis. The present goal is a measurement of the branching ratios of the various modes with momentum spectra for $K_{\mu 3}$ and K_{e3}.

From invariance arguments and the assumption of locality and the Universal Fermi Interaction for leptons, the matrix element for the decay K_{13}, where 1 is μ or e is

$$M=[f_+(P_\alpha+Q_\alpha)+f_-(P_\alpha-Q_\alpha)][\bar{\mu}_1(p)\gamma_\alpha(1+\gamma_5)\mu_\nu(q)],$$

P, Q, p, and q are the four-momenta of the K^+, π^0, lepton, and neutrino respectively, and the μ's are the usual Dirac spinors.

The theoretical interest lies in the determination of the form factors, f_+ and f_-, for it is there that the nature of the strong-interaction current becomes manifest. Previous branching-ratio measurements, performed mainly in heavy-liquid bubble chambers, have given results for the determination of ξ($\xi = f_-/f_+$) which are inconsistent with the measurement of ξ from polarization in $K_{\mu 3}$. A recent experiment by Auerbach et al.[1] employing a spectrometer and spark chambers similar to this experiment has given results consistent with the bubble-chamber results, but still inconsistent with the polarization data. To further clarify this situation and to reduce the uncertainty in ξ, this experiment was performed.

It is anticipated that the results of this experiment will yield 22 000 $K_{\mu 2}$, 6500 $K_{\pi 2}$, 350 $K_{\mu 3}$, and 350 K_{e3} decays. This will give not only a more significant measurement of ξ, but also a determination of the relative branching ratic of $K_{\mu 2}/K_{\pi 2}$ which will add to the reduction of the uncertainty of that number.

PION FORM FACTOR

Kenneth M. Crowe, Anthony Parsons, and Anthony Fainberg

We are studying the $\pi^{\pm}$-He differential elastic cross section in the region 50 to 90 MeV. The primary aim of the experiment is to obtain an estimate of the pion electromagnetic form factor, and we are hoping to isolate the electromagnetic interaction of the pion with the helium nucleus by measuring the difference between the π^+ and π^- cross section. This difference arises from the Coulomb nuclear interference term which has opposite sign in the two cases.

A preliminary experiment last year indicated the feasibility of the technique, and analysis of that data is essentially complete. We have now set up a beam at the 184-inch cyclotron and, using an array of 16 range telescopes, we are at present accumulating data.

The counters are linked to a PDP5 for preliminary analysis. In general, the rates and other factors are close to those envisaged in the design. Initial results show that the interference term varies considerably in the above

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1. L. B. Auerbach, J. Mac G. Dobbs, A. K. Marm, W. K. McFarlane and D. H. White, Phys. Rev. 155, 1505 (1967).

energy range, and we hope to survey the region completely. Calibration using pion-proton scattering is a necessary part of this experiment, but we also hope that any data will be an improvement over existing πp data in this region.

PIONIC X RAYS

Raymond Kunselman

Results on pionic x ray shifts and widths have been published by D. Jenkins* and R. Kunselman.[2] We have measured the 3d→2p, 4f→3d and 5g→4f π-mesonic x-ray energies and widths for a selection of isotopes from Z = 16 to Z = 94. Our objective was to measure shifts and widths of the pion energy levels caused by the strong-interaction force of the nucleus. We have combined the present data with earlier data[3] to find pion-nucleon interaction parameters and find fair agreement with values predicted from pion-nucleon scattering and pion production.

*Presently at Virginia Associated Research Center, Newport News, Virginia.

2. D. A. Jenkins and R. Kunselman, Phys. Rev. Letters 17, 1148 (1966).
3. D. A. Jenkins, R. Kunselman, M. K. Simmons, and T. Yamazaki, Phys. Rev. Letters 17, 1 (1966).

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NUCLEAR EMULSION GROUP

Harry H. Heckman in charge

TRAPPED PROTONS AT LOW SATELLITE ALTITUDES

Harry H. Heckman

The scanning and measuring of emulsions recovered from polar-orbiting satellites during the period of minimum solar activity has been completed. Between September 1962 and June 1966 we have examined the flux, energy spectrum, and east-west asymmetry of trapped protons with $E > 58$ MeV detected over the South Atlantic. Data from 27 satellite flights have been used in this work.

The most characteristic feature of the trapped protons is temporal stability. Since November 1962, the omnidirectional proton flux at 65 MeV has been constant within a standard deviation of ±10%. This result is in contrast with the calculated results of Blanchard and Hess,[1] who have shown that solar-cycle variations in the atmospheric density should produce flux variations up to a factor of two during this time. It is not now clear whether the apparent lack of solar-cycle effects is real or has been masked by the nonadiabatic redistribution that the protons suffered at the time of the Starfish test, July 1962. This question should be resolved shortly when our observations are extended to cover the current period of increasing solar activity -- a period during which the greatest changes in the inner proton belt are expected.

Because of the stability of the inner belt, we are able to combine all our data to determine the flux, east-west asymmetries, and particle scale heights as a function of altitude. We have concluded that these properties of the trapped radiation are all explained by atmospheric losses. The particle scale heights, H, are defined by $H^{-1} = d(\ln \mathfrak{J})/dh$, where $\mathfrak{J}$ is the unidirectional flux normal to the magnetic field line and h is the altitude. These heights H are used to determine atmospheric scale heights. Our measurements of atmospheric scale heights are in good agreement with those deduced from the model atmosphere of Harris and Priester.[2]

We find the omnidirectional flux J varies with altitude as $h^{4.84\pm0.12}$ for $200 < h < 450$ km. The particle scale height is thus given by $H = h/4.84$. The scale-heights determined by measuring the east-west flux ratios are, within their errors, consistent with this expression for H.

1. R. C. Blanchard and W. N. Hess, J. Geophys. Res. 69, 3927 (1964).
2. I. Harris and W. Priester, NASA X-640-63-145, 1963.

B-L SPACE AND GEOMAGNETIC FIELD MODELS

Harry H. Heckman and Peter J. Lindstrom

We have intercompared geomagnetic field models in B-L space for $B > 0.20$ gauss and $L < 2.0\ R_e$ (earth radii). Three field models were selected because of their general usage in the analysis of trapped radiation data: GSFC (9/65) (99 coefficient); Jensen and Whitaker (512 coefficient); and Jensen and Cain (48 coefficient). The geographic coordinates of constant B-L trajectories were computed using the 512 and 48 coefficient fields in both the southern and northern hemispheres. At each geographical point along the trajectories thus defined, B and L values were recalculated using different geomagnetic field models. We find that variations in B-L space exist between the 48 and 99 coefficient fields corresponding to maximum differences of $500 < \Delta B < 1100\gamma$ and $0.03 < \Delta L < 0.05\ R_e$, mainly in the southern hemisphere. This corresponds to maximum differences in the proton flux by factors of 1.2 to 10 within the region of B-L space examined. Between the 512 and 99 coefficient models, maximum differences in the proton flux by factors of 1.4 to 50 exist. Such differences in the proton flux due to model-dependent errors in B-L space demonstrate the need for careful reevaluation of existing data that pertain to possible time variations of inner belt protons.

APOLLO EARTH ORBITAL EXPERIMENT

Harry H. Heckman

Because of the cancellation of the Apollo 205 mission, the trapped-particle experiment S-16 has been postponed until a flight reassignment can be made.

STOPPING-POWER DIFFERENCES OF $\pi^{\pm}$ MESONS

Harry H. Heckman

The intensity of $\pi^{\pm}$ beams available at the 184-inch cyclotron during this report period were judged to be of insufficient intensity to obtain a meaningful measurement of the difference in stopping powers of low energy ($E \sim 1$ to 2 MeV) π^+ and π^- mesons via range-difference measurements. Based on the few measurements of this effect, we expect that the ranges of $\pi^{\pm}$ mesons at 1.65 MeV, i.e. ranges of $\sim 100\mu$, differ by about 3%. This represents an average difference in ionization over this range, and it is therefore quite possible that at smaller ranges the rate of ionization may be significantly greater than 3%. It is technically feasible to measure differences in ionization of this amount in suitably processed emulsion. As an alternate experiment, then, we exposed a stack of nuclear emulsions to about 10^5 π^+ and π^- mesons to measure the differences in the grain density, hence dE/dx, of $\pi^{\pm}$ mesons as a function of velocity.

A series of processing procedures were undertaken to decrease the amount of development in the emulsion so as to eliminate saturation due to high grain densities at the track endings -- while maintaining sufficient sensitivity to identify the sign of the charge of the stopping pion.

We found that G-5 emulsion, processed isothermally at 5°C with a developer strength of 1/16 normal gave a satisfactory emulsion for this experiment. Scanning has only begun, but the initial results demonstrate rather clearly that $dE/dx(\pi^-)$ is less than $dE/dx(\pi^+)$, perhaps by as much as 5 to 10% for ranges $\lesssim 10\mu$. The difference in ionization appears to diminish rapidly with range. Within the limits of our present statistics, no differences in ionization are observed for ranges $> 50\mu$.

PUBLICATIONS

Harry H. Heckman, Note on the Magnetic-Moment Adiabatic Invariant for Particle Motion in a Dipole Magnetic Field, UCRL-17308, December 1966.

PHYSICS RESEARCH

Edward J. Lofgren in charge

DIBOSON PRODUCTION BY 2- TO 5- GeV/c PIONS

Alan R. Clark, Bruce Cork,
Tom Elioff, Leroy T. Kerth,
T. N. Rangaswamy,
W. A. Wenzel

This experiment is to measure the diboson spectrum up to masses of about 1800 MeV. The reactions to be studied include:

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

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

with incident pion momenta at 3, 4, 4.5, and 5 GeV/c. Several regions of particular interest are the K^+K^- spectrum in the vicinity of the ψ(1020 MeV) and the f^0 (1250 MeV), the $\pi^+\pi^-$ spectrum in the ρ region (700 to 800 MeV), and the $\pi^+\pi^-$ spectrum around 1650 MeV, where structure has been reported recently.[1] Initial results from a previous experiment by this group[2] showed significant structure in the dipion spectrum near the ρ peak. This experiment should increase the statistics in this region considerably, and also provide better measurement precision. Data collection started in July 1966 and ended just a week prior to the Bevatron shutdown of December 1966. Approximately two million pictures were taken divided fairly evenly among the four different incident π^- momenta. Out of these we expect to have at least 200 000 analyzable events; the pictures are being scanned on SASS (Spark Chamber Automatic Scanning System). Scanning 24 hours a day, six days a week, the system is being utilized to its fullest capacity. The average scanning time is approximately 2 to 5 seconds per frame, depending on the film. The first round of scanning of the data at 5 and 4.5 GeV/c is almost complete, leaving the 3- and 4-GeV/c data to be scanned. The initial scan of the entire data is expected to be complete by the end of June 1967.

The SASS output tapes contain information on the data sequence, hodoscope information for better definition of incident π^- momentum, the spark coordinates for matched two-track events, and the coordinates for the fiducials. The computer program for reconstructing the tracks in three-dimensional space starting out with the spark and fiducial information is nearly finalized. The TRACK program for determining the momenta of two outgoing tracks is being modified to our special case, thereby reducing both time and core space on the CDC 6600. The reconstruction of tracks for the entire data is expected to commence about May 15, 1967 and the momentum analysis should start about the end of May.

1. CERN-Ecole Polytechnique Collaboration and Orsay-Milan-Saclay Collaboration, Phys. Letters 17, 354 (1965); Aachen-Berlin-CERN Collaboration, Phys. Letters 18, 351 (1965).
2. Carl M. Noble, Jr., Pion-Pion Interactions from π^-p Collisions at 3 and 4 BeV/c (Ph. D. thesis), UCRL-16655, February 1966.

MEASUREMENT OF THE $(K^+ \rightarrow e^+ + \nu) / (K^+ \rightarrow \mu^+ + \nu)$ BRANCHING RATIO

Charles M. Ankenbrandt, Alan R. Clark,
Bruce Cork, Tom Elioff, Denis Keefe,
LeRoy T. Kerth, John F. McReynolds,
David Newton, and W. A. Wenzel

A spark chamber experiment has been designed to measure accurately the $K_{e2}/K_{\mu 2}$ branching ratio. Most of the equipment has been constructed and is presently being tested.

500-MeV/c K^+'s with a ±2% momentum bite will be degraded in beryllium and stopped in a target of polyethylene (CH_2) approximately 5 in. from the median plane and on the axis of the M5 - Mark II magnet. The magnet field is shaped by the pole pieces and current configurations such that particles of the momentum range 230 to 247 MeV/c are focused to a region near a symmetric point on the magnet axis on the other side of the median plane. Focusing for other momentum ranges is being studied. The magnet will have 0.4 of 4π solid angle, giving approximately three K_{e2} events per hour at the predicted branching ratio, and giving 1000 to 1500 total events in the 500-h run.

Before triggering the spark chambers, particles will be momentum-analyzed by a double hodoscope of scintillation counters, one set at the outer range of particle orbits, the other near the axis to detect particles at both ends of the orbit. Velocity discrimination will be done by a 300-psi ethane-gas Cerenkov counter surrounding the target, and further muon and pion rejection will be made by having particles terminate their orbits in a lead cylinder in which electrons will lose far more energy due to bremsstrahlung. All of the scintillators have been constructed and most have been tested. Preliminary tests have been made on the Cerenkov counter, but because cosmic-ray fluxes are low, testing will have to wait for a parasitic beam from the Bevatron. As a further muon rejector, there will be a requirement that only two of the inner hodoscope scintillators give a count, because 235 MeV/c muons have some probability of passing through both walls of the lead absorber. The four rejection systems should keep triggers down to a tolerable level. Momentum will be analyzed and events rejected accurately by scanning spark chamber film.

Success of the experiment will depend mainly upon rejection of $K \rightarrow \mu\nu$, which is expected to be more frequent than $K \rightarrow e\nu$ by a factor of 4×10^4. It is estimated that the combined muon rejection will be at least 10^5.

The experiment will measure the electron spectrum from 220 to 247 MeV/c (228 MeV/c is the K_{e3} end point), which may include some events of the type $K \rightarrow e\nu\gamma$, where the γ ray has high energy, i.e., other than bremsstrahlung. Lead-scintillator γ counters covering 0.3 of a 4π solid angle combined with the K_{e2} measurement should give some γ-ray angular and electron energy-spectrum information on this decay, which so far has not been observed. In addition to the $K \rightarrow e\nu$ branching ratio, the 10%-momentum-bite focusing properties of the system make possible precise measurement of the $K_{\pi 2}/K_{\mu 2}$ branching ratio. There is presently a 4% discrepancy between measured values of this ratio.

NUCLEON—NUCLEON TRIPLE SCATTERING

C. M. Ankenbrandt, D. Cheng,* Leroy T. Kerth, K. C. Leung, and Pamela Surko

An experiment has been scheduled for September at the 184-inch cyclotron to measure the triple-scattering parameters $D^{(12)}$, R^{12} and $R'^{(12)}$ for the p-p, n-p, and p-n systems. The experiment will use a polarized neutron (proton) beam of known energy produced by scattering the cyclotron external proton beam on a deuterium (hydrogen) target at 15 to 30 deg in the laboratory system, to give incident kinetic energies of 550 to 670 MeV. These polarized nucleons will be scattered on deuterium or hydrogen, and the polarization of the outgoing proton or neutron analyzed in carbon.

Magnetostrictive spark chambers and a superconducting solenoid are the major items being designed and fabricated for this experiment.

*Member, Moyer-Helmholz Physics Group.

NEUTRAL LEPTONIC CURRENTS

Charles M. Ankenbrandt, Alan R. Clark, Bruce Cork, Denis Keefe, Leroy T. Kerth, David Newton, and W. A. Wenzel

The possibility is being explored of detecting muon or electron pairs produced by the decay of the long-lived $K_L^0 \rightarrow \mu^+ + \mu^-$ or $K_L^0 \rightarrow e^+ + e^-$. The branching ratio may be as low as 10^{-8}, so a large-solid-angle detection system with a very good trigger is required to discriminate against other decay modes. A large magnet would be used to analyze the secondaries. Spark chamber detectors with a range requirement on the muons would help to reduce background.

SEARCH FOR MASSIVE PARTICLES IN COSMIC RAYS

Bruce Cork

An experiment has been completed in collaboration with a University of Michigan Group and a University of Wisconsin Group to detect long-lived particles that might be produced in the upper atmosphere. The experiment, sponsored in part by the NSF, AEC, NASA, and ONR, was conducted at Echo Lake, Colorado, 10 600 ft above sea level.

A paper is nearly prepared giving the results of the measurements. The experiment was sensitive for energetic particles having a mass of 5 to 15 GeV. After 1500 h of operation with an aperture of 0.78 m^2-sr, only one anomolous event was found. This represents an upper limit to the flux of these particles of approximately $10^{-10} (cm^2\text{-sec-sr})^{-1}$.

PUBLICATIONS

C. M. Ankenbrandt, Nucleon Isobar Production in Proton-Proton Collisions from 3 to 7 GeV/c (Ph. D. Thesis), UCRL-17257, December 1966.

PHYSICS RESEARCH

Burton J. Moyer and A. Carl Helmholz in charge

μ^--CAPTURE γ-RAYS

Selig N. Kaplan

In connection with our investigation of the role played by giant resonances in the μ^- capture process, a preliminary experimental run has just begun at the 184-inch cyclotron. Set up and running parasitically behind a low-energy π^- experiment, we are able to stop 1000 μ^- per sec in a thick target (4 by 4 in. by 5 gm/cm^2). This stopping rate will be ample to allow efficiency calibration of our Li-drifted-Ge γ spectrometer with μ-mesic x rays, but will probably not be sufficient to allow a detailed study of nucleon γ-ray spectra. A high-intensity run with beam control is planned in the fall.

$\pi^- p \rightarrow \pi^0 n$ POLARIZATION EXPERIMENT

Thomas Risser

This experiment has been dropped from the Bevatron schedule and postponed indefinitely. The equipment is largely completed and is being stored at the Howard Terminal.

p-He^3 POLARIZATION FROM 10 TO 20 MeV

W. F. Tivol, P. J. Clark, H. E. Conzett, J. S. McKee, and R. J. Slobodrian

Data processing is still in progress.

COMPARISON OF THE LIFETIMES OF POSITIVE AND NEGATIVE PIONS

David S. Ayres, David O. Caldwell, Allan W. Cormack, Virgil Elings, Arthur J. Greenberg, Robert W. Kenney, and Rollin J. Morrison

Since last October equipment has been built and tested for use in the new experiment. In particular, considerable effort has been devoted to:

(a) Developing techniques for assembling the flasks of both liquid hydrogen Cerenkov counters, including construction of satisfactory cylindrical and 45-deg mirrors used inside the flasks.

(b) Monitoring the temperature and other operating conditions in the flask of the monitor liquid-hydrogen Cerenkov counter for long periods.

(c) Building, testing, and rebuilding wire spark chambers for the beam finder and the magnetic spectrometer.

(d) Development of the nuclear-magnetic-resonance technique for monitoring the bending-magnet fields at distances of over 100 ft.

Setup of the beam for the new experiment has been started at the 184-inch cyclotron, and wire orbiting is now in progress.

π^- + He^4 INTERACTIONS

L. Kaufman, V. Perez-Mendez, S. Williams, B. Gauld, and J. Sperinde

The experiment was completed February 17, 1967 and a month and a half was spent in completing the analyzing program.

All π^- events are analyzed now, and we expect to complete work on the proton spectrum with a month. This is to yield evidence on the final state of the neutrons in the $\pi^- + He^4 \rightarrow p + 3n$.

Work on the π^+ spectrum has just started, and we expect to have all of our data by June. This reaction involves double charge-exchange for the pion.

HELIUM-FILLED WIDE-GAP CHAMBER PROJECT

A. Stetz, V. Perez-Mendez, and J. Sperinde

We are using a wide-gap streamer chamber to study the effectiveness for polarization analysis of helium for 70- and 80-MeV protons. Using the low energy proton beam at the 184-inch cyclotron as described in the previous report, we have photographed 50 000 p-He events. These events are being measured on the TRAMP scanning and measuring tables. Analysis programs have been written to calculate the polarization and differential cross section as a function of angle from the TRAMP output. Eventually 200 000 frames will be scanned. This will result in 5000 events at 70 and 80 MeV.

$\pi^0\pi^0 n$ EXPERIMENT

Thomas Risser and Richard D. Eandi

In collaboration with some members of Alvarez Group at LRL, we are now preparing a spark-chamber experiment at the Bevatron to study the reaction $\pi^- p \rightarrow n\pi^0\pi^0$ between 1.5 and 2.5 GeV/c. The principal purpose of the experiment is to analyze the $\pi^0\pi^0$ system in a search for scalar mesons and to measure the π-π phase shifts.

Other goals are to measure the branching ratios of the neutral decay modes of the $\eta(550)$ and $\omega(783)$ mesons from the reactions $\pi^- p \rightarrow n\eta(550)$ and $\pi^- p \rightarrow n\omega(783)$, respectively.

The reaction will be identified by detecting all the final-state particles. The detection equipment will consist of a set of very large spark chambers to detect γ rays and a set of neutron counters to measure neutron time of flight from the liquid-hydrogen target at all polar laboratory angles from about 20 to 80 deg with respect to the incident beam direction. The spark chambers are between seven and eight radiation lengths thick and form five of the six faces of a cube with the target at the center, so that the solid angle for detection of γ-rays is large.

According to the present Bevatron schedule, the setting up of the equipment at the accelerator is to begin in October with the experiment then to start about 2 to 3 months later. Twenty-five periods of Bevatron time have been allotted for tune-up and 40 periods for taking data. In this running time we anticipate collecting about 8000 events of the desired type to study peripheral production of the diboson $\pi^0\pi^0$ system.

$K_L^0 \rightarrow \pi^0 + \pi^0$

D. Cheng, R. Eandi, A. C. Helmholz, R. W. Kenney, I. Linscott, W. Oliver, S. Parker, C. Rey (LRL); D. Caldwell, (UCSB); R. Cence, B. Jones, V. Peterson, V. Stenger (University of Hawaii)

Analysis of 22 000 frames taken with the triggering set for neutral decays gave three events satisfying all criteria for the decay $K_L^0 \rightarrow 2\pi^0$. With an assumed branching ratio $K_L^0 \rightarrow 2\pi^0/K_L^0 \rightarrow 3\pi^0 = 1.9\times10^{-3}$, an average of about five such events would be expected in such a sample. From the data taken so far, the number of $3\pi^0$ events giving four showers and not satisfying the kinematics does not appear to be serious, although of course the number of events is far too small to show a peak due to $2\pi^0$ decay and thus substantiate this. These data correspond to about 8 h of running time at our expected beam level (20% of the internal beam) and is about 1/3 of our total data. Most data were taken at reduced beam levels (1 to 3% of the internal beam) to prevent interference with experiments having presently higher priorities.

A change in the method of triggering the chambers for neutral decays has been tested for use when running at higher beam rates where we will be limited by camera speed. It will reduce spurious triggers by nearly a factor of two, while reducing our $K_L^0 \rightarrow 2\pi^0$ triggering efficiency by a factor of only 0.8. The spark-gap high-voltage recovery time has also been reduced to 80 msec in anticipation of the higher beam.

The large fraction of four shower K decays seen (10% of all decays compared to a Monte Carlo calculation of 2% expected) are now essentially understood. Much of it comes from a number of 1% and 2% effects that were not included in the first version of the Monte Carlo program, such as showers from $K \rightarrow 3\pi^0$ decay that begin and end within the triggering counters. (We detect such events, for instance, when a data light indicates the counter triggered and no shower satisfying our minimum criteria is found near it.) These first Monte Carlo results are in adequate agreement with the data on five- and six-(visible) shower events from $K \rightarrow 3\pi^0$ decay, and a more detailed and accurate program is planned for final comparison with the data. Work is continuing on analysis programs, Monte Carlo programs, and programs to analyze the $K_L^0 \rightarrow \pi^+\pi^-\pi^0$ events that will be used in measuring the K_L^0 flux and energy spectrum, the gamma-detection efficiency, and the angular accuracy of measured gamma directions.

Preliminary calculations have been completed to see if the phase of η_{00} could be determined by measuring the intensities from interfering K_L^0's and regenerated K_S^0's. Further time on the amplitude measurement will be necessary before a reliable answer can be given.

K_{e4} EXPERIMENT

B. Gauld, V. Perez-Mendez, and V. Z. Peterson

Design work on this experiment has progressed in the following areas

(a) Two alternative K beams have been considered in detail for the experiment. The possibility of using a wedge-shaped energy degrader to narrow down the momentum spread of the K mesons entering the magnetic-field region in which the decays occur looks promising and may produce a K decay rate 50 to 100% higher than the more conventional beams.

(b) Model tests on the aluminum-plated Mylar cylindrical spark chambers are underway preparatory to constructing the whole spark-chamber array.

(c) Various Monte Carlo and multiple-scattering calculations have been done to evaluate the errors in the momentum analyses of the decay pions and electrons needed for the kinematic reconstruction of the events.

SLAC EXPERIMENT

A. Boyarski, F. Bulos, R. Diebold,
R. Larsen, D. Leith and B. Richter (SLAC);
L. Kaufman, V. Perez-Mendez
and A. Stetz (LRL)

Four spark chambers and their associated triggering equipment have been sent to SLAC for a preliminary run to measure the momentum spread and background of the 8-GeV monochromatic photon beam produced by positrons at end station B (SLAC).

The chambers and the readout electronics have been connected to the 1800 IBM computer on-line. Tests on the whole system using muons at end station B from another target available upstream have shown that so far the data storage, on-line monitoring display, and momentum-analysis programs are now in working order.

An additional phase of this experiment has been submitted to the SLAC scheduling committee. This request for extra running time is for the purpose of measuring the yield of f^0 mesons produced specifically by a diffraction mechanism involving the exchange of a Pomeranchon. This process, if it occurs, is an electromagnetic C-violating mechanism, and hence is of current interest.

Since the equipment, beam, layout, and personnel are identical with those involved in the ρ^0, ϕ^0 experiment, this additional time is expected immediately after the original experiment is completed.

MAGNETOSTRICTIVE READOUT DEVELOPMENT FOR SPARK CHAMBERS

V. Perez-Mendez and Ronald Grove

Methods for improving the multiple-spark readout efficiency by limiting the spark currents are being tested. The residual magnetic properties of the Fe-Co alloys we use for the readout are also being checked for use with the smaller spark currents thus available in multiple-spark events.

The uniformity of response of the large spark chambers such as we are using at SLAC has been improved by the addition of aluminum-plated Mylar sheets placed close to the chamber wires. These sheets charge the chamber's capacity directly and minimize the interference of the series inductance of the wires. Further improvement is obtained by the use of artificial-delay-line-shaped voltage pulses which can be used satisfactorily with these modified chambers.

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David Cheng, Nucleon-Nucleon Scattering Experiments at Intermediate Energies in Berkeley, UCRL-17904, March 23, 1967.

PHYSICS RESEARCH

Wilson M. Powell and Robert W. Birge in charge

EXPERIMENTAL STUDY OF K_{e4} DECAY

Powell-Birge Group

The scanning and measuring of the K_{e4} events in the Berkeley portion of the film is now complete. Our collaborators in London and Wisconsin have also virtually completed their scans. We expect approximately 300 events of which data on 241 were presented to a Conference of the British Physical Society held in London in April by our collaborators at University College, London.

Our conclusions, based on more events than in the last Semiannual Report, are essentially unchanged, the only difference being that we are beginning to see a significant vector contribution to the interaction which was not so apparent with the smaller number of events. The significance of this will have to await more detailed analysis.

π^+p INTERACTIONS IN THE MOMENTUM INTERVAL 1.3 THROUGH 1.7 GeV/c

Powell-Birge Group

In November and December we took approximately 130 000 pictures of π^+p in the 72-inch chamber. These were taken at three energies: 50 000 pictures at 1.34 GeV/c, 40 000 at 1.445 GeV/c, and 40 000 at 1.685 GeV/c. This represents just under half of our original request, the rest being scheduled in the 25-inch chamber.

This film has been completely scanned and measured for all associated production events (a total of approximately 6000). All four-prongs (approximately 15 000) have also been scanned and measured, and about one-sixth of the two-prongs (15 000) have been measured.

Analysis of the data is still in a preliminary state.

π^+p INTERACTIONS IN THE MOMENTUM INTERVAL 2.9 THROUGH 4.3 GeV/c

David G. Brown, Robert W. Birge, Robert P. Ely, George Gidal, and George E. Kalmus

We are making a detailed analysis of π^+p four-prong interactions between 3 and 4 GeV/c incident π^+ momentum. Of particular interest are $N^{*++}\rho^0$, $N^{*++}\omega^0$, and other quasi-two-body final states. T-channel effects seem to dominate at these energies, as shown by the exponential shape of the momentum-transfer distribution. A "dip" behavior near t = - 0.4 has been observed for $N^{*++}\rho^0$ similar to that observed in elastic scattering, and the forward peak appears to shrink with increasing incident momentum. For the much shallower $N^{*++}\omega^0$ distribution, a dip is indicated at t = - 0.8, and a backward peak is evident. The t dependence of the density matrix elements seems in basic agreement with peripheral-model predictions, although there are some discrepancies. The cross sections for these reactions are being studied and means sought to identify s-channel effects, especially from the T = 3/2 nuclear resonance, $N^*(2850)$.

THE REACTIONS $K^-n\to\Lambda\pi^-$ AND $K^-p\to\Lambda\pi^0$

Robert P. Ely, George E. Kalmus, and Wesley M. Smart

We are trying to extend the partial-wave analysis from our data in the energy region 1660 through 1900 MeV[1] to the data of Wohl, Solmitz, and Stevenson (1900 through 2100 MeV).[2] Preliminary results indicate that we can obtain more precise information on the Y_1^* resonances in the higher energy region.

K^-n AND K^-d ELASTIC SCATTERING

George E. Kalmus and Nathan Jew

Scanning and measuring for K^-d elastic scattering have essentially been completed, and the data are being analyzed. Efforts are continuing to scan for long protons in order to study the effects of double scattering on the K^-n elastic data.

$K^-p\to\Lambda\pi^0$ AND $K^-p\to\bar{K}^0n$

Robert P. Ely and James Louie

Λ Lifetime

With improved statistics over those of the previous Semiannual Report, our hydrogen data (13 000 events) for the reactions $K^-p\to\Lambda\pi^0$ and $K^-p\to\Lambda\pi^+\pi^-$ yield a lambda lifetime of 2.62±0.03, and our deuterium data (8700 events) for the reactions $K^-n\to\Lambda\pi^-$ and $K^-n\to\Lambda(n\pi)$ yield 2.57±0.03, in units of 10^{-10}

1. W. M. Smart, A. Kernan, G. E. Kalmus, and R. P. Ely, Jr., Phys. Rev. Letters 17, 556 (1966).
2. C. G. Wohl, F. T. Solmitz, and M. L. Stevenson, Phys. Rev. Letters 17, 107 (1966).

sec. Combining the samples gives $\tau_\Lambda = (2.60\pm0.02)\times10^{-10}$ sec.

Absorption Model

The $Y_1^*(1765)$ and $Y_0^*(1815)$ are s-channel resonances in K^-p interactions, and calculations have begun to see if a peripheral model with absorption will explain the background amplitudes when the final states are $\Lambda\pi$ and $\bar{K}^0n$.

$K^-p \to \Lambda\pi\pi$

Jack S. Sahouria

In the last Semiannual Report the method of analysis was discussed briefly. If we assume that $K^-p \to Y^*(1385) + \pi$, then $Y^*1385 \to \Lambda\pi$. A computer program has been written to calculate Dalitz-plot density for the above process, incorporating base symmetry under exchange of pions, and the interference effects of I-spin states. The Dalitz plots are calculated for different LL' J separately, where L is the initial partial wave in the K^-p system, L' is the orbital-angular-momentum state in the $Y^*\pi$ system, and J is the total angular momentum. By fitting the data to a series of contributions (to Dalitz plots) from the above (LL' J) waves, one can ascertain I-spin content and the partial waves contributing to the above process. A program to do this fitting has been written and the process of fitting is in progress.

In the calculated plots discussed above one sees that the interference $(Y^{*+}\pi^-, Y^{*-}\pi^+)$ has a sizeable effect on the mass position of $Y^*(1385)$ and its resonance shape. It is very likely that this is the reason that previous measurements of $Y^*(1385)$ mass have been different from one another by as much as 5 MeV or more.[3]

$K^-p \to \Sigma^\pm\pi^\mp$ AND $K^-n \to \Sigma^-\pi^0$

Robert B. Bell

We are carrying out a partial-wave analysis on a sample of 4500 $\Sigma^+\pi^-$, 3500 $\Sigma^-\pi^+$, and 500 $\Sigma^-\pi^0$ events in the K^-N center-of-mass energy range from 1700 to 1850 MeV. In addition to the well-known $Y_0^*(1820)$, the data require the presence of a new D_5 I = 0 resonance with a mass of 1830 MeV and a width of 65 MeV. We will also be able to make some statements about other S = - 1 isobars in and near our energy region. Scanning and measuring is now in progress with the aim of doubling the number of $K^-p \to \Sigma^\pm\pi^\mp$ events.

3. A. H. Rosenfeld, A. Barbaro-Galtieri, W. J. Podolsky, L. R. Price, P. Soding, C. G. Wohl, M. Roos, and W. J. Willis, Data on Particles and Resonant States, UCRL-8030 Rev, Pt. I, January 1967.

EXPERIMENTAL STUDY OF K_{e3} DECAY

George E. Kalmus and Anne Kernan*

This work has been reported in ("Experimental Study of $K^+ \to \pi^0 + e^+ + \nu$ Decay," UCRL-17351, and will be published in the Physical Review.

ELECTRONS IN HEAVY-LIQUID BUBBLE CHAMBERS

George E. Kalmus and Daniel F. Kane

We have studied the effects of radiation energy loss, ionization energy loss, and multiple scattering of intermediate-energy (5- to 500-MeV) electrons in heavy liquids. A computer program was written to generate electron tracks in heavy-liquid bubble chambers to determine detection efficiency and the correctness of the Behr-Mittner formula for determining electron energy. The latter was found to be good if a correction for ionization loss is added, but it is hoped that the electron program can be used to determine a more efficient method.

K67 BEAM DESIGN

George E. Kalmus, Danield F. Kane, and Perry S. Shers

An all-purpose beam for the 25-inch chamber is essentially designed and the manufacture of components has begun. This is a collaborative effort between the above members of the Powell-Birge group and John Kadyk, Ralph Butler, and Donald Coyne of the Trilling-Goldhaber group. The parameters of the beam are given in their section of the Semiannual Report.

*Now at Stanford Linear Accelerator Center, Stanford, California.

DATA REDUCTION

Robert W. Birge and P. Wes Weber

Summary of Scanning and Measuring

With an average of 25 (full-time equivalent) visual-measurements personnel, the following data reduction was accomplished in the past six months:

SCANNING

Experiment No.	Bubble chamber	Beam	Number of frames
Conventional system			
32	25-inch hydrogen	850 to 1150 MeV/c K^-	158 203
34	25-inch deuterium	850 to 1150 MeV/c K^-	313 743
36	72-inch hydrogen	3.3 GeV/c π^+	87 110
37	72-inch hydrogen	3.7 GeV/c π^+	83 487
38	72-inch hydrogen	3.5 GeV/c π^+	71 283
39	72-inch hydrogen	3.9 GeV/c π^+	36 405
40	72-inch hydrogen	3.9 GeV/c π^+	100 900
42	72-inch hydrogen	1.68 GeV/c π^+	99 195
43	72-inch hydrogen	1.4 GeV/c π^+	87 654
44	72-inch hydrogen	1.35 GeV/c π^+	70 315
		Subtotal	1 108 295
FSD system			
32	25-inch hydrogen	850 to 1150 MeV/c K^-	28 334
36	72-inch hydrogen	3.3 GeV/c π^+	950
37	72-inch hydrogen	3.7 GeV/c π^+	2 139
38	72-inch hydrogen	3.5 GeV/c π^+	661
39	72-inch hydrogen	2.9 GeV/c π^+	508
40	72-inch hydrogen	3.9 GeV/c π^+	2 411
41	72-inch hydrogen	4.1 GeV/c π^+	886
42	72-inch hydrogen	1.68 GeV/c π^+	24 522
43	72-inch hydrogen	1.4 GeV/c π^+	39 579
44	72-inch hydrogen	1.35 GeV/c π^+	33 033
		Subtotal	133 023
		Total	1 241 318

MEASURING

	Measuring hours	Number of events	Events per measuring hour
Conventional System (two measuring microscopes,* two MP1-type Franckensteins)			
	4 985	22 195	4.5
FSD System (two SP5B-type image-plane digitizers)			
	3 005	48 980	16.3
Total	7 990**	71 175	8.9

*One measuring microscope out of service 3/15/67 to go on-line to COBWEB data reduction system to be completed 5/15/67.

**Includes training time.

Computer-Controlled Data Reduction System (COBWEB)

The first stage of the COBWEB system being built to attach measuring machines on-line to the IBM 7044 is nearly completed. The electronics for the first machine and the entire interface have been built and debugged and the main logic program is now being tested. The parts for the second, third, and fourth machines are on order, and wiring will start soon.

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G. Gidal et al., Measurement of $K^+_{\mu 3}$ Decay Parameters, UCRL-16593, January 3, 1966; Phys. Rev. 150, 1153 (1966).

G. E. Kalmus and A. Kernan, Experimental Study of $K^+ \rightarrow \pi^0 + e^+ + \nu$ Decay, UCRL-17351, January 26, 1967; to be published in Phys. Rev.

PHYSICS RESEARCH

Emilio Segrè and Owen Chamberlain in charge

π-MESIC ATOM X-RAY EXPERIMENT

Raymond Kunselman, Clyde Wiegand, and David Weldon

Work on π-mesic atoms is continuing at the cyclotron. The purpose of the experiment is to measure the number of π-mesic x rays produced by pion transitions between the Bohr-like orbits, per pion stopped in the target. Several representative elements are being used for targets, and all transition lines between 26 and 300 keV are being investigated. The present data will be combined with previous data obtained over a higher energy range. From the data, the initial capture distribution of the pion in the atomic states about the nucleus, and the pion cascade down through the Bohr-like orbits will be deduced.

STUDY OF $K^+ \rightarrow \pi^+ + 2\gamma$

Min Chen, David Cutts, Martin Deutsch,* Peter Kijewski, Rae Stiening, and Clyde Wiegand

We have used the data from our $K_{\mu 3}$ experiment to search for the decay $K^+ \rightarrow \pi^+ + 2\gamma$. It has been proposed from time to time that K and η decays go through a $\sigma\,(0^+)$ meson intermediate state. If this is so, the experimental observation of the large branching ratio for $\eta \rightarrow \pi^0 + \sigma \rightarrow 2\gamma$ would imply that one should observe the decay mode $K^+ \rightarrow \sigma + \pi^+$, $\sigma \rightarrow 2\gamma$. A simple model predicts that the branching ratio for this decay should be 0.4%.

On the basis of an analysis of 10% of our data, we can set an upper limit of 10^{-4} on the branching ratio for this decay. This rate is less than one-tenth the rate expected from the σ model.

MEASUREMENT OF K^--MESONIC X RAYS FROM Li, Be, B, AND C

Clyde E. Wiegand and Dick A. Mack

When K^--mesons stop in matter, x rays are emitted as the mesons cascade into nuclei. We measured the energy and yield of several x-ray spectral lines from the light elements.[1]

*Present address: Massachusetts Institute of Technology.

1. C. E. Wiegand and D. A. Mack, Phys. Rev. Letters **18**, 685 (1967).

A more comprehensive experiment is being planned with emphasis on the use of K^- mesons as probes of the nuclear surface, as suggested by Denys Wilkinson in the new journal Comments on Nuclear and Particle Physics.[2] We will also try to observe energy-level shifts due to perturbation of the orbits by Kaon-nucleon forces.

PROTON-PROTON AND PROTON-NEUTRON INTERACTIONS AT 6 GeV/c

P. Condon, W. Chinowsky, W. Gage, R. Kinsey, S. Klein, M. Mandelkern, P. Schmidt, and J. Schultz*

A paper on the three-body strange particle events in the proton-proton film has been prepared and will be submitted to the Physical Review within a few days. The four- and five-body strange-particle analysis is showing interesting preliminary results. In particular, we find a strong enhancement in the region of the proposed κ meson (723-MeV Kπ) which we have not been able to account for via kinematic reflections.

Analysis of the four and five body non-strange-particle events is in its final stages. We feel it is possible to interpret much of this data in terms of quasi-two-body final states with cascade decay of higher N^*'s. Such an interpretation is complicated however by the difficulty in making unambiguous assignments of the pions to various stages of decay.

We are presently engaged in a program of rapid measurement of two-prong events in the proton-proton film. We have preliminary indication that the $N^*(1400)$ is present in the three-body events, and we are accumulating statistics on this channel.

The first scan of the proton-deuterium film for strange-particle events has been completed, but only an insignificant amount has been measured, since we feel the two-prong proton-proton work is more interesting at present. The non-strange-particle events in proton-deuterium are being measured on the FSD. Some necessary computer-program modifications have been completed, and we will start getting the results of kinematic fitting on these events within a few weeks.

2. Denys Wilkinson, Comments Nucl. Particle Phys. **1**, 36 (1967).

*Present address: University of California, Irvine, California.

A second exposure of protons on deuterium, but at 8 GeV/c, is being made now at the Brookhaven 80-inch bubble chamber. The film from this exposure will be shared with the group at the Irvine campus of the University of California. This exposure will total about 75 000 pictures.

PHASE-SHIFT ANALYSIS OF $\pi^{\pm}p$ ELASTIC-SCATTERING EXPERIMENTS

Claiborne H. Johnson, Jr., Owen Chamberlain, Paul D. Grannis,* Michel J. Hansroul,† and Herbert M. Steiner

The phase-shift analysis of $\pi^{\pm}p$ elastic scattering begun in 1966 is still in progress. There are two main aspects to this work:

(a) Search for sets of phase shifts which reproduce the experimental observations. This is done by starting with a set (or possibly sets) of solutions obtained at lower energies and then continuing these solutions up with energy. The program MINFUN has been adapted to make rough quick searches involving rather extensive portions of the phase-shift space. More complete and precise determination of the phase shifts is subsequently made by use of the program VARMIT. In making these searches we rely heavily on the recent $\pi^{\pm}p$ polarization data obtained by our group.

Substantial progress has been made in this part of the analysis. Satisfactory fits have been made to the data at 17 energies from 500 to 1300 MeV, and a number of essentially different solutions obtained at each energy. From this collection of solutions one can select a sequence that exhibits reasonably smooth behavior with energy. This sequence is in qualitative agreement with previous analyses by other groups.

(b) In conjunction with the search for phase-shift solutions we are investigating problems associated with uniqueness of these solutions. In particular we are concerned with possible ambiguities, and we are studying ways of eliminating them.

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POLARIZATION IN $\pi^{+}p$ AND $\pi^{-}p$ ELASTIC SCATTERING FROM 250 TO 410 MeV

William Gorn, Charles C. Morehouse, Thomas M. Powell, Peter R. Robrish, Stephen Rock, Stephen Shannon, Herbert M. Steiner, and Howard Weisberg

Data taking, using the polarized proton target, was completed in mid-April, 1967. The data are being analyzed to find the polarization parameter at four energies for the angular region $70 \lesssim \theta_{c.m.} \lesssim 180$ deg. Subsequent analysis will determine phase-shift solutions in this energy region, hopefully unambiguously. An attempt will be made to use the solution(s) thus found to reduce the number of solutions that have been found at higher (Bevatron) energies.[3]

A preliminary phase-shift analysis at 310 MeV allowed us to choose unambiguously between the existing solutions. The measured polarization parameter for $\pi^{+}p$ elastic scattering is in good agreement with the Lovelace Bareyre phase-shift predictions, but a few degrees change in these solutions is required to obtain agreement with the measured $\pi^{-}p$ polarization parameters.

POLARIZED-PROTON TARGET IMPROVEMENTS

Owen Chamberlain, Herbert M. Steiner, Howard Weisberg, and Gilbert Shapiro

One of the most suitable target materials now seems to be a mixture of ethyl alcohol and water, doped with a free radical. Proton polarization of 35% has been obtained in a field of 25 kG. This material is advantageous whenever the target is required to be thin as measured in radiation lengths.

An alcohol target is expected to be fairly resistant to radiation damage, though tests of this property must be made before it will be reasonable to use such a target in a strong electron beam, such as that at SLAC.

A magnet and horizontal cryostat are to be constructed. The magnet should give good field homogeneity over the target material at an operating field of 25 kG, and such a magnet is being designed. It is intended that a reasonable large equatorial opening angle should be available--about 26 deg--to allow counting scattered particles over a large solid angle. The cryostat is being considered. It may be of the type designed by P. Roubeau of the

3. See M. J. Hansroul et al., in PDSR, UCRL-17282, January 1967, p. 49.

Saclay laboratory in France. Such a design offers the prospect of cost savings through lessening of the amount of liquid helium consumed in the operation of the target, although some effort would be needed to get design and operation experience with the rather sophisticated Roubeau design.

Work is still in progress toward stabilizing the magnetic field and microwave frequency. Initially, the frequency will be measured rather than automatically corrected. If improvements in performance warrent automatic stabilization, that feature will be added in the future.

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PHYSICS RESEARCH

Howard A. Shugart in charge

ATOMIC BEAM GROUP

The Atomic Beam Group continues to devote the major portion of its effort toward the systematic measurement of atomic and nuclear properties of radioactive isotopes. This research furnishes knowledge of parameters such as the nuclear spin, the electronic angular momentum, the nuclear multipole moments, the electronic g_J factor, the hyperfine interaction energy between the nucleus and electrons, and other more intricate interactions. In the long run these properties are used as input information in the evaluation of atomic and nuclear theories and also provide valuable starting points for nuclear spectroscopic studies. All techniques employed in this work involve systems in which the atom is essentially unperturbed by neighbors, as in the atomic beam method, or the atom is subjected to infrequent collisions, as in the optical-pumping or electron-impact excitation methods.

Owing to the relative simplicity of the system under study, interpretation of results assumes a particularly unambiguous form. This, coupled with the sensitivity of these methods makes studies of rare radioactive species a productive endeavor.

Beyond the measurement efforts, the group explores new techniques which hold promise of revealing better understanding of physical laws and tries new applications of our standard methods. Along this line, Calaprice, Commins, Dobson, Gibbs, and Wick have recently completed a study of time-reversal invariance in the beta decay of ^{19}Ne, utilizing an atomic neam, decay-in-flight apparatus.[1]

1. F. P. Calaprice, E. D. Commins, H. M. Gibbs, G. L. Wick, and D. A. Dobson, A Test of Time-Reversal Invariance in the Beta Decay of Ne^{19}, UCRL-17477, March 31, 1967; Phys. Rev. Letters 18, 918 (1967).

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2. Michael Herbert Prior, Nuclear Spin and Hyperfine-Structure Measurements on the Radioactive Isotopes In^{110}, Sn^{121}, and Rb^{88} (Ph. D. Thesis), UCRL-17472, March 25, 1967.

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3. T. Hadeishi and C.-H. Liu, Resonance Absorption Beats Due to Coherent Excitation of Nondegenerate Metastable Atomic Sublevels by Electron Impact, UCRL-17386 Abstract, February 7, 1967.
4. T. Hadeishi and C.-H. Liu, Exchange Collisions Between the Ionic Ground State and the Neutral Metastable State of Atoms Formed and Aligned by Electron Impact, UCRL-17342 Abstract, January 19, 1967; presented at the Fifth International Conference on Physics of Electronic and Atomic Collisions, Ioffe Physico-Technical Institute, Leningrad, July 17-23, 1967.
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PHYSICS RESEARCH

George H. Trilling and Gerson Goldhaber in charge

The experimenters involved in this work are Roger W. Bland, Michael Bowler,* Ralph Butler, Jonathan Chan, Donald Coyne, Alex Firestone, Chumin Fu, Peter Gaposchkin, Gerson Goldhaber, Sulamith Goldhaber,** Alan Hirata, John Kadyk, Jimmy MacNaughton, Yona Oren,† Bertram M. Schwarzschild, Victor Seeger, Benjamin Shen, George Trilling‡ and Charles Wohl.

K_2^0 INTERACTIONS AND DECAYS

Work has continued on the low-energy K_2^0 experiment, an exposure of the 25-inch hydrogen bubble chamber to a pure K_2^0 beam with a momentum of about 250 MeV/c. About 400 000 useful photographs were obtained, with an event seen about every seventeenth frame.

K_2^0 Decays

Using the bubble density of the secondary particles, we have carefully examined a subsample comprising about 20% of the total data, in order to identify the principal decay modes. These events will be used to check performance of automatic flying-spot-digitizer (FSD) measurement of bubble density on the remaining 80% of the sample. We expect that this analysis will yield detailed results on the branching ratios and absolute decay rates for charged decay modes, as well as distributions in the various modes.

An analysis based on more than 500 K_{e3}^0 decays shows that the K_{e3}^0 form factor is consistent with no energy dependence, with as small a statistical error as any previously reported. This result disagrees with certain other K_{e3}^0 experiments. Our total sample, with many times our present number of K_{e3}^0 decays, should yield a very precise result. (JK, JC, DC, YO, BCS, GHT)

K_2^0p Interactions

The entire sample of interactions has been measured, and analysis of K_2^0 charge exchange, $K_2^0p \rightarrow K^+n$, has begun. This, it is hoped, will yield an improved result for the S = + 1, I = 0 scattering length. Several hundred events are expected. Analysis of the entire sample has also begun at about 2400 interactions yielding a V. (JK, GT, YO, GG, SG)

K^+p AND K^+d INTERACTIONS FROM 860 TO 1580 MeV/c

We have film, taken in the 25-inch bubble chamber, in hydrogen at 860, 910, 960, 1080, 1280, 1360, and 1580 MeV/c, and in deuterium at 860, 960, 1200, 1360, and 1580 MeV/c. These momenta span the region of the peaks observed by Cool et al.[1]—one in the I = 1 K^+p total cross section at 1250 MeV/c, and one in the I = 0 total cross section (obtained from K^+p and K^+d measurements) at 1150 MeV/c. It is very important for all symmetry schemes, and especially for quark models, to determine if these peaks are resonances.

K^+p Elastic Scattering

We have obtained semifinal K^+p elastic-scattering cross sections at 860, 960, 1200, and 1360 MeV/c. The results show no obvious structure to be associated with the I = 1 Cool peak. The elastic cross section begins to decrease at about 800 MeV/c, where the inelastic cross section becomes appreciable, and continues to fall off smoothly to the highest energies. As determined by this and other experiments, the differential cross section (dcs) is flat below 600 MeV/c, except for interference with the Coulomb amplitude in the forward direction; the only sizeable nuclear phase shift is the $S_{1/2}$. Between 600 and 800 MeV/c the dcs acquires a positive $\cos^2\theta$ component. At 860 MeV/c, there is a small and negative $\cos^3\theta$ component. As the momentum further increases, the dcs shifts rapidly to diffraction-like peaking in the forward direction. At 1200 MeV/c and above, the dcs in the forward hemisphere fit well the form $d\sigma/dt = \alpha e^{-\beta|t|}$, where t is the momentum transfer. The parameter β increases with increasing momentum, reflecting a shrinking of the diffraction peak. We are engaged in obtaining results at the other momenta and in a phase-shift analysis of the results. (CW, RWB, JC, GG, SG, VS, GHT)

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*Present address: Oxford University, England.

**Deceased.

†Present address: Tel Aviv University, Israel.

‡On sabbatical leave from CERN, Geneva, Switzerland.

1. R. L. Cool, G. Giacomelli, T. F. Kycia, B. A. Leontic, K. K. Li, A. Lundby, and J. Teiger, Phys. Rev. Letters 17, 102 (1966).

K^+p Inelastic Final States

Data from this experiment and others show a peak in the KN^* cross section at about 1150 MeV/c, related to but slightly below the T = 1 Cool peak.[1] In order to look for a resonance decaying mainly into the KN^* final state, we have performed a partial-wave analysis of the N^* production in the $K^0\pi^+p$ final state at 0.86, 0.96, 1.2, and 1.36 GeV/c. We find that the $P_{1/2}$ and $P_{3/2}$ waves are largest and contribute about equally to the KN^* cross section throughout the region of the Cool bump. No rapid phase variation is apparent. This is inconsistent with any simple resonance hypothesis, and suggests that the KN^* bump is a threshold effect. (RWB, MB, JC, GG, SG, VS, GHT, CF)

K^+d Interactions

The present analysis is concentrated on charge-exchange scattering,

$$K^+d \rightarrow K^0 p\, p, \tag{1}$$

and inelastic processes such as

$$K^+d \rightarrow K^+\pi^- p\, p. \tag{2}$$

Preliminary results indicate that in this momentum range the cross section for reaction (1) is falling, whereas the cross section for inelastic processes is rising rapidly. Furthermore, the differential cross section for charge-exchange scattering seems to become increasingly forward-peaked as momentum increases. We hope to do a partial-wave analysis of this reaction. At the three higher momenta, reaction (2) appears to be strongly dominated by K^{*0} formation. The production mechanism for K^* production is presently under investigation. (AH, SG, GG, GHT, RWB, JK, CW, BS, BMS, VS)

π^+p INTERACTIONS FROM 3.5 TO 3.9 GeV/c

Two experimental runs with π^+ incident on the 72-inch hydrogen chamber were concluded in December 1966. Beam momenta included several steps from 3.5 to 3.9 GeV/c. Analysis of the set of about 180 000 pictures started in January, and as of April, about 12 000 events have been measured and fitted. Results are not yet available from this subsample, but it alone should provide statistical accuracy comparable to previous experimental investigations of B, A_1; A_2, ρ, η, and η' production at these momenta. The total sample should help to resolve ambiguities due to statistical limitations in the previous experiments. (DC, RB, PG, JM)

K^+p INTERACTIONS AT 9 GeV/c

We have begun the study of 100 000 photographs of K^+p interactions at 9 GeV/c. The film was taken in October 1966 in the Brookhaven National Laboratory 80-inch hydrogen bubble chamber exposed to an rf-separated K^+ beam. The Berkeley cameras were used.

Eleven charged anticascade hyperons have been observed in a rapid scan. This corresponds to a cross section of about 5 μb, distributed among the final states $\Xi p\Lambda^0$, $\Xi p\Sigma^0$, $\Xi\Sigma^+n$, $\Xi\Sigma^+$ (missing mass), Ξp (missing mass) and $\Xi\pi^+\Lambda^0 n$. The production angular distributions of the final-state particles are consistent with isotropy.

We are analyzing reactions leading to three, four, and five particles in the final state from a sample of approximately 40 000 events measured on the FSD. In the four-particle final state, we are studying the structure of the $K\pi\pi$ mass enhancement in the mass region from 1.2 to 1.5 GeV. We also observe a $K\pi\pi$ mass enhancement at about 1.74 GeV which can probably be identified with the previously reported L meson. (AF, BCS, GG)

BEAM DESIGN

New 25-Inch Bubble Chamber Beam

The design for a semi-permanent two-stage separated beam to be used with the 25-inch hydrogen chamber is nearly complete, and fabrication of components has begun. An exchange between vertical acceptance and separation should make possible operation between 1 and 2 GeV/c for K^-, and perhaps somewhat beyond these limits for K^+. Operation with π^+, π^-, and protons, without changing the physical arrangement, seems possible up to 3.2 GeV/c. The momentum bite is adjustable over wide limits and can be made as large as 4%. It seems probable that this beam will never require more than 1/4 of the Bevatron internal beam in order to provide 15 particles in the bubble chamber. A beam destroyer will be available to accurately determine the desired number of tracks, and use of a beam stepper seems possible below 2 GeV/c. (JK, DC, RB)

High-Energy Beam Optics (General)

We have investigated the use of strong sextupoles for large vertical chromatic corrections, and have incorporated the results into the beam-optics program TRAMP. Beam designs using such elements are complicated by the nonnegligible momentum asymmetries introduced in the horizontal plane.

We have also developed a program which considerably aids in the design of beams and testing the stability thereof. The program, DOUBMAP, provides a contour map of the gradients and (or) magnifications of a quadrupole doublet, as a function of image and object points. The new feature is that all requirements in both planes are simultaneously considered, and the only available solutions (if any exist) are graphically displayed. The utility of this program has been demonstrated by predicting useful solutions with such unorthodox combinations of parameters that they would probably otherwise be overlooked. (DC, JK, RB)

PUBLICATIONS

Gerson Goldhaber, "The Search for Hyperons and Bosons Belonging to Higher Symmetries," in Symmetry Principles at High Energies–Fourth Coral Gables Conference, January 1967 (W. H. Freeman and Co., S. F. and London, 1967)

B. M. Schwarzschild and W. Rarita, Regge Fitting to K^+n Charge Exchange and Other Meson–Nucleon Processes, Bull. Am. Phys. Soc. 12, 472 (1967).

C. G. Wohl, R. W. Bland, M. G. Bowler, J. L. Brown, G. Goldhaber, S. Goldhaber, and G. H. Trilling, K^+p Elastic Scattering Around the 1910-MeV Mass Peak, Bull. Am. Phys. Soc. 12, 506 (1967).

A. Firestone, R. W. Bland, G. Goldhaber, J A. Kadyk, B. C. Shen, and G. H. Trilling, Study of Meson Production in K^+p Interactions at 9 BeV/c, Bull. Am. Phys. Soc. 12, 540 (1967).

B. C. Shen, R. W. Bland, A. Firestone, G. Goldhaber, J. A. Kadyk, B. Sheldon, and G. H. Trilling, Ξ Hyperon Production in K^+p Interactions at 9 BeV/c, Bull. Am. Phys. Soc. 12, 541 (1967).

J. A. Kadyk, J. Chan, D. Drijard, Y. Oren, B. Sheldon, and G. H. Trilling, Determination of the Energy Dependence of the K^0_{e3}—Decay Form Factor, Bull. Am. Phys. Soc. 12, 568 (1967).

R. W. Bland, M. G. Bowler, J. L. Brown, G. Goldhaber, S. Goldhaber, V. H. Seeger, and G. H. Trilling, Inelastic Processes Near the T = 1 K^+p Peak at 1250 MeV/c, to be published in Phys. Rev. Letters.

DATA HANDLING

Howard S. White in charge

COMPUTER-PROGRAM DEVELOPMENT

HAZE

Routine production operation continued on the real-time HAZE program (420). A more flexible fiducial specification format was introduced, and the appropriate changes to the program logic were inserted. (Joyce Crawford)

The scan-tape editing program (422) was modified to allow a different event- and track-naming scheme to be used for the Segre-Chamberlain Group. Routine production operation continued. (Carol Osborne and Jim Greene)

The FSD calibration program (434) was reassembled to include the calibration calculation (formerly done in FORTRAN) as well as the fiducial-finding subprogram. Operation under the TRIST executive allows immediate on-line response to questions arising during HAZE or DAPR production runs. Debugging of the reassembly was completed. (Bud Koger)

A detailed study of the SPVB scan-table calibration was undertaken. It was discovered that a small view dependency existed on some tables, causing poor track overlay. By combining the calibration coefficients from the three views, it was possible to substantially improve the throughput ratio for all tables. (Joyce Crawford, Dennis Hall, and Howard White)

FOG

The FOG three-view geometry program 140 continued in routine production operation. A prototype subprogram for matching tracks in one view with tracks in another view was written and debugged. The results of this program produced the design specifications for the DAPR match subprogram and ultimately will be used in FOG as part of the event-repair procedure. (Joan Franz, Dennis Hall)

Program 137, which preprocesses microscope and Franckenstein data for input to program 140, was generalized to handle data for all current experiments. (Frank Windorski)

CLOUDY

Routine production operation of the CLOUDY programs continued. Extensive work was done on the problem of convergence in the kinematical-constraints subprogram for the case of very-high-energy K_0 decays. The solution was found, and the appropriate changes to the program were inserted.

The problem of Σ decays was also studied, and the two-vertex charged connecting case was improved. Work is continuing in this area.

An improvement was made to the CLOUDY Library generating program (208) which greatly facilitates elimination of unwanted mass permutations. (Vivian Morgan and Dennis Hall)

FAIR

The FAIR system of programs continued to operate in routine production operation. The ionization calculations developed in the preceding six months were extended to operate on the older data which contained information for one view only. The new procedure proved to be extremely successful in resolving mass ambiguities.

The FAIR Library generating program (304) was modified to supply more information about events with tape errors, both in the form of tallies and a detailed catalog listing of each error. Frequency of IBM 7094 tape problems has increased significantly during the last year.

The FAIR output program (305) was extended to allow two or more histograms to be summed. (Loren Shalz and Dennis Hall)

TRIST

Complete documentation of the TRIST operating system was started. Debugging of B-level logic required for DAPR was nearly completed. Routine operation of A-level (real-time) and C-level (background) priority programs continued. (Carol Osborne)

Several long-standing bugs were removed from the DAP assembly program, and the assembly print format was changed to permit convenient use of the UPDATE feature of the program, and to allow printing on notebook-sized paper. (Bud Koger)

EVENT ACCOUNTING

The event-accounting (EA) system of programs produced and kept up-to-date event-accounting master tapes for experiments 11, 13 through 17, 36 through 44, 70, 71, 90, and 91 (see Events-Measurement table under DATA PROCESSING OPERATIONS).

About 320 000 physical events were abstracted onto EA master tapes. These experiment master tapes contain the scanning, measuring, and reconstruction history for each physical event within the experiment. Some of the additions to the master-tape generating programs were (1) the logic to correlate as the same physical event FSD measured and Franckenstein measured, (2) the provision for carrying coded comments on the EA library, and (3) the flagging of "scan only" events on the EA library. Events flagged in this manner do not appear on measurement request lists.

Program 606, which obtains CLOUDY data for the EA system from CLOUDY library tapes, was debugged, but was not yet considered a standard production program.

Program 607 was written and debugged. Its function is to delete or modify selected data on a packed EA tape, as requested.

Program 604, which is used to summarize packed EA tapes, was provided with several new options. In addition to catalogs and roll summaries, generation of assignment-list summaries was provided. Error profile by scanner, measurer, scan table or microscope with a ranking function were also made available with the dates as a variable. These summaries allow maintenance of quality- and performance-control procedures.

Current development effort is being applied toward obtaining the EA source tape concurrently with regular production runs on Fog, etc., and to add range information to the EA tape formats. (Shirley Buckman)

Program 435, which produces an unpacked EA source tape from scan tapes, was reassembled to allow up to two coded comments on the source tape, and to include an indicator mark for events scanned in the "identify only" mode. The XY coordinates were changed to reflect a position in the beam plane rather than on the top glass. (Carol Osborne)

DAPR

The production version of the A-level, track-abstraction program 511 was debugged, and the real time ability was verified. Work was started on obtaining complete documentation and a clean assembly. (Joan Tyson)

Debugging of the track-joining-and-linking portions of program 512 as well as the input-output section continued. Track joining consists of identifying and recombining into a single track the several units of those tracks which were segmented in the track-following process; track linking consists of combining several different scans of a picture into a single image. The joining phase of 512 was debugged, and debugging on the linking phase was started. (Joyce Crawford, Ken Lynn, and Frank Windorski)

The production version of the vertex-finding, vertex-matching, and track-matching program 513 was flow-charted and partially coded and debugged. The program first generates a list of provisional vertices in each view by looking for tracks that appear to converge at a point. The next operation consists of rejecting all provisional vertices that do not have a corresponding vertex in at least one other view. Finally the tracks in each vertex are matched with their corresponding images in the other views, and the results are written onto the Data Abstract Tape. (David Budenaers, Joyce Crawford, Dennis Hall, and Howard White)

The DAPR diagnostic program 515 was generalized to accept data from any level of DAPR output. Design specifications for the online quality monitor (OQM) and for the final-scanning program 516 were determined. (Nan Jontulevic and Joan Franz)

DATA-PROCESSING OPERATIONS

The following tables summarize the processing of both Franckenstein- and FSD-measured events. An event is the entire collection of related vertices measured in a bubble chamber picture. New measurements are counted separately, but the effect of any reprocessing has been eliminated from the totals.

Event Measurements Analyzed

Experiment	Chamber (and Laboratory, if other than LRL)	Beam	Group	Number of events
Franckenstein Measurements				
28	30-inch propane-Freon	Stopping K^+	Powell-Birge	6 333
32	25-inch hydrogen	0.8 to 1.2-GeV/c K^-	Powell-Birge	593
34	25-inch deuterium	0.9 to 1.2-GeV/c K^-	Powell-Birge	4 293
35	100-cm propane-Freon (CERN)	Stopping K^+	Powell-Birge	145
36	72-inch hydrogen	3.3-GeV/c π^+p	Powell-Birge	4 857
37	72-inch hydrogen	3.7-GeV/c π^+p	Powell-Birge	1 303
38	72-inch hydrogen	3.5-GeV/c π^+p	Powell-Birge	703
39	72-inch hydrogen	3.0-GeV/c π^+p	Powell-Birge	490
40	72-inch hydrogen	3.9-GeV/c π^+p	Powell-Birge	293
42	72-inch hydrogen	1.68-GeV/c π^+	Powell-Birge	860
43	72-inch hydrogen	1.43-GeV/c π^+	Powell-Birge	891
44	72-inch hydrogen	1.35-GeV/c π^+	Powell-Birge	800
				21 561
FSD Measurements				
11	25-inch hydrogen	0.3-GeV/c K_2^0	Trilling-Goldhaber	3 006
14	25-inch deuterium	1.2-GeV/c K^+	Trilling-Goldhaber	1 126
15	25-inch deuterium	1.2-GeV/c K^+	Trilling-Goldhaber	1 711
16	25-inch hydrogen	1.2-GeV/c K^+	Trilling-Goldhaber	3 147
17	25-inch deuterium	860-MeV/c K^+	Trilling-Goldhaber	6 791
32	25-inch hydrogen	0.8 to 1.2-GeV/c K^-	Powell-Birge	6 397
36	72-inch hydrogen	3.3-GeV/c π^+p	Powell-Birge	146
37	72-inch hydrogen	3.7-GeV/c π^+p	Powell-Birge	5 522
38	72-inch hydrogen	3.5-GeV/c π^+p	Powell-Birge	56
40	72-inch hydrogen	3.9-GeV/c π^+p	Powell-Birge	1 190
42	72-inch hydrogen	1.68-GeV/c π^+p	Powell-Birge	7 806
43	72-inch hydrogen	1.43-GeV/c π^+p	Powell-Birge	12 836
44	72-inch hydrogen	1.35-GeV/c π^+p	Powell-Birge	5 721
70	72-inch hydrogen	6.0-GeV/c p	Segrè-Chamberlain	11 031
71	72-inch deuterium	6.0-GeV/c p	Segrè-Chamberlain	9 115
90	80-inch hydrogen (BNL)	9.0-GeV/c K^+	Trilling-Goldhaber	49 544
91	72-inch hydrogen	3.5-GeV/c π^+	Trilling-Goldhaber	9 662
			Total Events Analyzed	156 368

HEALTH PHYSICS

H. Wade Patterson in charge

HEALTH PHYSICS ACTIVITIES

Installation of logarithmic radiation intensity indicators was completed at the 88-inch cyclotron. A fast-acting beam-cutoff device, capable of acting within 1 to 3 μsec, to prevent accidental radiation exposure to personnel, was designed and tested. Development of general-purpose, transistorized counting equipment in modular form continued with the participation of the Physics Technical Support group.

A shielding study has been performed at the 88-inch cyclotron. Nearly maximum-energy ion beams of alphas, protons, and deuterons were stopped in a thick tantalum target. The attenuation of the secondary-neutron radiation was studied in a stack of ten precision-cast ordinary concrete blocks. Effects of 12-in. faces of iron and uranium in place of the first 12-in. of concrete were also studied. Neutron attenuation lengths and neutron spectra at successive 3-in. depths in concrete are being determined from data analysis now in progress, as are effects of 12-in. iron or depleted-uranium faces upon the attenuation lengths and spectra of neutrons produced by each type of ion beam. A total of nearly 700 detectors, including aluminum, nickel, thallium, and gold were weighed, labeled, positioned, irradiated, and counted. These data are being computer-analyzed. The information is being applied to the design of local shielding to be used in the new high-energy-resolution cave No. 4, with a possible cost savings of about $200 000 over the cost of a completely shielded cave. Future applications can be made in shielding proposals of the 48-inch cyclotron.

Work was completed on an experiment at the CERN proton synchrotron to provide information for the design of shielding for the 200-GeV accelerator. Attenuation of the PS radiation was measured in earth as a function of angle and energy from a target. The collected data are now being treated, and it is expected that a report will be issued in two or three months.

PUBLICATIONS

R. P. Omberg and H. W. Patterson, Application of the Stars Produced in a Nuclear Emulsion to the Determination of a High-Neutron-Energy Spectrum, UCRL-17063, February 1967.

J. B. McCaslin and D. Stephens, High-Sensitivity Neutron and Proton Flux Detector with a Practical Threshold near 600 MeV, Using Hg (Spallation) ^{149}Tb, UCRL-17505, April 14, 1967.

ACCELERATOR OPERATION AND DEVELOPMENT

ACCELERATOR STUDY GROUP

Edward J. Lofgren in charge

STUDY GROUP ACTIVITIES

In December, the AEC announced the selection of an area at Weston, Illinois (30 miles west of downtown Chicago) as the site for the proposed 200-GeV accelerator. Authorization of the project is still pending, and a staff for the next design and construction phase is being formed by the Universities Research Association. Meanwhile, the LRL Design Study Group is continuing to refine elements of the 1965 Design Study Report (UCRL-16000) and has begun work in several new areas. Some work has been reduced or discontinued, too, so the level of effort in the Study Group remains at about 60 people.

Design refinements include alternate arrangements of the injector synchrotron. Smaller ring circumferences are being considered, which lead ot less azimuthal length of straight sections available for components. It appears that the required functions can be achieved more easily in a 1/8 main-ring-circumference FOOFDOD arrangement than in the 1/7 main-ring-circumference FOFDOD arrangement shown in the Design Study Report.

Work in new areas includes an analysis of the feasibility of constructing a synchrotron whose peak energy can later be extended substantially higher than original design levels. The studies, started in November 1966, have resulted in practical initial guide-field configurations that provide for a later conversion to higher energy by the addition of magnets, rf accelerating gaps, and other components. These arrangements would be suitable in principle for accelerators designed initially for 200 GeV, but extendable to 300, 400, and 500 GeV. The practicality and economy of these alternatives are yet to be investigated.

By regarding the initial provision for extendible energy as only an option for future improvement of the accelerator, we have emphasized that initial cost penalties must be low. This consideration has resulted in less circumference for a given final energy design than would be economic or appropriate for an accelerator intended for operation initially at that energy.

To simplify the future conversion to higher energy and to take advantage of accumulated operating experience, it has been judged desirable to retain the basic orbit parameters through the conversion. Examples of extendable lattices have been developed that retain the same ν value and approximate beam size.

Another new area is the development of superconducting dc beam-transport elements to help establish a firm basis for an eventual decision on whether to outfit the experimental areas for superconducting or conventional magnets. A superconducting solenoid is being built, which will provide valuable design and operating experience for this development program.

Volume III or 200-BeV Accelerator: Studies on Experimental Use (UCRL-16830) was issued in February. It constituted the results of a Summer Study held at Berkeley in 1966 which had as its major topic the experimental use of the proposed 200-GeV Accelerator. Some physicists who did not attend the Summer Study submitted reports that they felt belonged in the volume, and these results were incorporated. Contents of this Summer Study volume are as follows:

200 BeV ACCELERATOR: STUDIES ON EXPERIMENTAL USE
VOLUME III
SUMMER STUDY - 1966

Contents

PUBLICATIONS

William M. Gibson and Harold A. Wollenberg, Investigations for Ground Stability in the Vicinity of the Calaveras Fault, Livermore and Amador Valleys, Alameda County, California, UCRL-17265, November 8, 1966.

W. S. Gilbert and D. Keefe, 200 BeV Accelerator: Studies on Experimental Use, Vol. III, UCRL-16830, February 1967.

Robert B. Meuser, Secondary Beam Magnets for the 200 BeV Accelerator--Conventional or Superconducting?, UCRL-17269, February 1967.

Roland Krevitt, Remote Maintenance Techniques Proposed for the 200 BeV Accelerator, UCRL-17195, February 1967.

Michael A. Green, The Use of Aluminum Coils Instead of Copper Coils in Accelerator Magnet Systems, UCRL-17258, February 1967.

Peter T. Clee and H. Paul Hernandez, A Ceramic Vacuum Chamber for a Fast-Cycling Proton Synchrotron, UCRL-17254, February 1967.

H. Paul Hernandez, The Selection of a Lamination Shape for a Fast-Cycling Alternating Gradient Magnet Core, UCRL-17264, February 1967.

W. W. Salsig, Capability vs. Cost for Servicing and Handling System Choices in 200 BeV Accelerator Design Study, UCRL-17247, February 15, 1967.

F. B. Selph and J. M. Peterson, Selection of Injector Synchrotron Parameters to Minimize Cost of the 200 BeV Accelerator, UCRL-17191, February 17, 1967.

William S. Gilbert, Radiation Problems with High-Energy Protron Accelerators, UCRL-17141, February 21, 1967.

Alper A. Garren, Glen R. Lambertson, Edward J. Lofgren, and Lloyd Smith, Extendible-Energy Synchrotrons, UCRL-17471, February 21, 1967.

Jack M. Peterson, Choice of the Injector System for the 200 BeV Accelerator, UCRL-17222, February 27, 1967.

R. L. Fleischer, E. L. Hubbard, P. B. Price, and R. M. Walker, Criterion for Registration in Dielectric Track Detectors, General Electric Report No. 66-C-424, November 1966; Phys. Rev. 156, 353 (1967).

Andris Faltens and Manfred Giesch, Fast Kicker Magnets for the 200 GeV Accelerator, UCRL-17246, November 1966.

H. Hernandez, R. B. Meuser, and W. W. Salsig, Mechanical Design Features of the 200 BeV Accelerator, ASME Preprint - 66-WA/NE-23 (1966); presented at the Particle Accelerator Engineering Conference, New York, December 1966; UCRL-16944, June 23, 1966.

BEVATRON

E. J. Lofgren in charge

BEVATRON ACTIVITIES

The Bevatron beam was operational for experimenters 87.1% of the scheduled operating time. On December 19, 1966, a fracture was discovered in the dovetail section of one of the rotor poles of the main motor-generator sets. This fracture was discovered during a routine Monday maintenance period. Further examination of the motor-generator sets showed cracks in over 50% of the sixteen rotor poles in both generator sets. Bevatron operation was suspended until May 1967, during which time new poles were fabricated and installed.

Westinghouse Electric Corporation was the original manufacturer of the motor generator sets. They still had the dies and jigs for the pole tips and were awarded the contract of making 16 new pole tips. Delivery of the new pole tips was scheduled and completed by March 1, 1967. During this shutdown, the motor generator sets were completely overhauled.

Because of the extended period necessary to repair the motor generator sets, we decided to speed up planned construction work on the new external-proton-beam (EPB) channel. A shutdown had been planned for summer 1967 to remove the old EPB channel and the bubble chamber building. A new shielding foundation and shielding would then be installed. Over the long period, we would lose less operating time if we could start the shielding construction during the first few months of 1967. Engineering design was speeded up and the jobs put out for bid.

The job of removing the old concrete floor along the EPB line started February 27. Installation of the new shielding foundation is scheduled to be completed by May 1. Removal of the bubble chamber building is scheduled to be complete about May 15. Roof construction on the first two and one half bays of the new EPB hall started in December and was completed on the first of March.

Operation of one channel of the new EPB system is scheduled to start early in July 1967. Complete operation in both EPB channels is expected to start about October 1967.

The Bevatron magnet has settled somewhat unevenly since the last alignment in 1962. The resultant vertical misalignment of the Bevatron magnet sectors causes a perturbation in the closed orbit of the beam. This shift in the closed orbit caused the beam to be low by about 0.9 in. in the north straight section. This is in the experimental target area for internal targets, and is believed to have been causing some problems in secondary particle yield. The beam was 0.75 in. high in the south straight section, where the extraction-system target is located. This misalignment may have been responsible for some reduction in EPB extraction efficiencies we have had lately. The extraction efficiency was being investigated when the motor-generator failure occurred. The Bevatron magnet was placed on a new tilted plane during this shutdown such that the closed orbit will again be on the gap centerline.

A new magnet was designed and installed in the east straight section to study the possibility of using resonant extraction for our external proton beam. If it works we hope to be able to eventually raise the extraction efficiency from our present 40%.

The need for more space in the main control room has grown as the complexity and flexibility of the Bevatron and experiments have increased. To take care of this need, the main control room console area and rack space was increased.

During this shutdown period some repairs and studies were carried out by the injector group. Vacuum leaks were repaired in four linac drift tubes and the alignment of all the drift tubes was checked. The linac E field and the wall H field were measured using a field-perturbation system and the PDP-5 control computer. These measurements were made as part of a program to study the dynamics of the linear accelerator and to provide a check on the computational programs being developed for new machine design.

The second Bevatron users meeting was held on January 21, 1967. Current topics in high-energy physics were discussed together with the future Bevatron program and schedule of experiments. Plans for the 200-BeV proton accelerator at Weston, Illinois were presented by Norman Ramsey.

More complete details of Bevatron operation for this period are given in the Bevatron Operation and Development reports for the fourth quarter 1966[1] and the first quarter 1967.[2]

1. Kenneth C. Crebbin and Robert Frias, Bevatron Operation and Development 52, UCRL-17402, May 23, 1967.
2. Robert W. Allison, Jr., Kenneth C. Crebbin, and Robert Frias, Bevatron Operation and Development, 53, UCRL-17543, June 2, 1967.

PUBLICATIONS

D. W. Morris, J. T. Tanabe, and E. Zajec, Copper-Tape-Wound, Edge-Cooled Solenoid, UCRL-17262, January 1967; presented at National Particle Accelerator Conference, Washington, D. C. March 1-3, 1967.

184-INCH CYCLOTRON

David L. Judd in charge

Reported by James T. Vale

No report was written for this Semiannual Report.

ELECTRON LINEAR ACCELERATOR

Douglas W. Pounds

OPERATIONS

During the period November 1966 through May 1967 utilization of the machine was as follows:

Biomedical research	384 hours
Bevatron	13 hours
Judd-Ruby Physics	8 hours
Maintainence and modifications	184 hours

The remainder of the time was devoted to linac development and general duties.

RESEARCH PROGRAMS

The research programs carried on at the linac during this period included radical spectra studies at 4.2°K, irradiations of enzyme systems, ghost irradiations of red blood cells, radiation damage of hydraulic oils, nuclear isomer studies, and linac development studies.

Detailed reports describing the results of these studies are contained in the annual reports of the departments concerned.

LINAC RESEARCH AND DEVELOPMENT

The short-pulse linac system is progressing as expected. Step one, the nanosecond injector system, is in the test-stand stage. Steps two and three are as reported in the previous semiannual report.[1]

PROGRAM SUMMARY

The expected commencement of the pulse-radiolysis program, to be conducted by the Warren Garrison nuclear chemistry group, failed to materialize. However, the system is mostly complete and may begin operating in the coming half year. The outlook for the other programs is for a continuation of the 4.2-deg E. P. R. studies, an expansion of the nuclear isomer program, a return of the chemical evolution studies, and a continuation of the enzyme irradiation studies.

1. Douglas W. Pounds, Physics Division Semiannual Report, May through October 1966, UCRL-17282, January 1967.

PERMUTED KEYWORD INDEX

The following pages are an alphabetical permuted index of the material in this report. Author's names are included. The index was prepared by the IBM-1401 computer using the key-word-plus-title program KWPT. All significant words are indexed; insignificant words have been automatically rejected by the computer.

In some cases, the titles have been edited slightly to ensure proper word combination during automatic indexing and to provide maximum meaningful information. For most sections covering multiple subjects in detail but not having subtitles, the editor has provided appropriate titles for adequate indexing of each subject.

Indexed terms are alphabetized and displayed in the left column of the index. The middle column shows the complete title and authors. The page number is given in the right column. Following the word index is the number index, which treats numbers as key-words.

Your comments about the usefulness of this index and possible improvements are invited. Address such comments to Miss Gloria Smith, who is responsible for the automated indexing, or to the editor, Mr. Gerald Behman.