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PHYSICS DIVISION SEMIANNUAL REPORT
May through October 1963

Berkeley, California

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GENERAL PHYSICS RESEARCH

PHYSICS RESEARCH

Luis W. Alvarez in charge

RESEARCH WITH BUBBLE CHAMBERS

Research projects reported below have been carried out by the following (as indicated by the initials at the end of each report):

Margaret H. Alston (MHA), Luis W. Alvarez (LWA), Jared A. Anderson (JAA), Angela Barbaro-Galtieri (AB-G), J. Peter Berge (JPB), Suh Urk Chung (SUC), Bevalyn B. Crawford (BBC), Frank S. Crawford, Jr. (FSC), Orin I. Dahl (OID), Joseph Doyle (JD), Stanley M. Flatte (SMF), Robert L. Golden (RLG), Ronald A. Grossman (RAG), Lyndon M. Hardy (LMH), Richard I. Hess (RIH), J. Richard Hubbard (JRH), Robert W. Huff (RWH), William E. Humphrey (WEH), Afzaal Hussain (AH), Darrell O. Huwe (DOH), Laurance D. Jacobs (LDJ), George R. Kalbfleisch (GRK), Ronald Levine (RL), James Lindsey (JL), Lester J. Lloyd (LJL), Gerald Meisner (GM), Deane Merrill (DM), Donald H. Miller (DHM), James R. Morris (JRM), John Munson (JM), Joseph J. Murray (JJM), LeRoy R. Price (LRP), Alan Rittenberg (AR), Arthur H. Rosenfeld (AHR), Ronald R. Ross (RRR), Janice B. Shafer (JBS), Frank Shively (FS), Daniel Siegal (DS), Gerald A. Smith (GAS), Frank T. Solmitz (FTS), M. Lynn Stevenson (MLS), Robert D. Tripp (RDT), Charles G. Wohl (CGW), and Stanley G. Wojcicki (SGW). A number of physicists have been associated with the development of new film-measuring devices: Humphrey, Ross, and Munson with the SMP, and Wojcicki and Luke Blaskovich with the Spiral Reader. New research activity in the magnetic monopole field was initiated recently by Luis W. Alvarez, Arnold J. Schwemin (AJS), Robert G. Smits (RGS), and Robert D. Watt (RDW).

Associated Production Experiment (72-Inch Chamber)

Neutral Branching Ratios of the η Meson

The existence of the mode $\eta \rightarrow \gamma\gamma$ (established by Chrétien et al.) has been confirmed. The branching ratio, determined for the first time, was found to be

$$(\eta \rightarrow \gamma\gamma) / (\eta \rightarrow \pi^+ \pi^- \pi^0) = 1.25 \pm 0.61.$$

The existence of the $\eta \rightarrow 3\pi^0$ decay mode was established directly, and the branching ratio

$$(\eta \rightarrow 3\pi^0)/(\eta \rightarrow \pi^+\pi^-\pi^0) = 0.83 \pm 0.32$$

was obtained. These data were published in Phys. Rev. Letters.¹
(FSC and LJL in collaboration with E. C. Fowler)

Final-State Interactions in the Decay $\eta \rightarrow \pi^+ + \pi^- + \pi^0$

The Dalitz plot for $\eta \rightarrow \pi^+\pi^-\pi^0$ was found to be in poor agreement with earlier compilations, in which $\approx 15\%$ background and $\approx 25\%$ $\pi^+\pi^-\gamma$ events were not subtracted. The distribution of events in the Dalitz plot was found to be in poor agreement with the "linear-matrix-element" theories; it appears to be quite compatible with the dipion-resonance hypothesis of Brown and Singer. Results have been submitted to Phys. Rev. Letters.²
(FSC, RAG, LJL, LRP, and E. C. Fowler)

Sign of the $K_1^0 - K_2^0$ Mass Difference

Data on secondary K^0 -p scatterings indicate that $m_2 > m_1$. However, phase-shift solutions that include D waves have not yet been tried, nor have phase shifts been varied within their error limits. Results have appeared in a laboratory report.³ (GM, RLG, BBC, FSC)

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

No violation of charge independence was found in a comparison of $\pi^- + p \rightarrow \Sigma^- + K^+$ and $\pi^- + p \rightarrow \Sigma^0 + K^0$ with published data for $\pi^+ + p \rightarrow \Sigma^+ + K^+$. The π^- data were from film taken at 1170 MeV/c incident-pion momentum. (Preliminary data were reported at the April 1963 APS meeting in Washington)

The polarizations of the Σ^- and Σ^0 are being studied. Also the Σ^- decay parameters are being determined by studying the scattering of the neutron from Σ^- decay and observing the asymmetry in the n-p scatters. (JAA, FSC, JD, RL)

The Reaction $\pi^- + p \rightarrow \Lambda + K$

A phase-shift analysis will be done for $\pi^- + p \rightarrow \Lambda + K$ with a recently completed IBM 7094 program. Cross-section and polarization data at incident momenta of 1030 and 1170 MeV/c are available in the Alvarez Group;

1. F. S. Crawford, L. J. Lloyd, and E. C. Fowler, Phys. Rev. Letters 10, 546 (1963).
2. Frank S. Crawford, Jr., Ronald A. Grossman, L. J. Lloyd, LeRoy R. Price, and Earle C. Fowler, Final-State Interactions in the Decay $\eta \rightarrow 3\pi$, UCRL-11075, (October 1963) submitted to Phys. Rev. Letters.
3. Gerald W. Meisner, Robert L. Golden, Bevalyn B. Crawford, and Frank S. Crawford, Sign of the $K_1^0 - K_2^0$ Mass Difference, UCRL-11018 (September 1963). Preliminary results were also given by F. S. Crawford at the Brookhaven Conference on Weak Interactions, September 1963.

additional data are available from the University of Wisconsin for 1125, 1225, 1275, and 1325 MeV/c. The use of these, with the previously published data of Bertanza et al., should permit the determination of a suitable set of phase shifts and hence an understanding of the states contributing to the peak in the ΛK cross section at 1030 MeV/c.

(JAA, BBC, FSC, RLG, LJL, GM)

Magnetic Moment of the Λ

Analysis is in its final stages for the determination of the magnetic moment of the Λ . The two existing measurements by other experimenters give results of -1.5 ± 0.5 and 0.0 ± 0.5 nuclear magnetons. The expected precision of this experiment is ± 0.7 nuclear magneton.

(JAA, FSC)

K-72 Experiment (72-Inch Chamber)

Study of $K\pi(\pi)$ Final States

The reactions $K^- + p \rightarrow \bar{K}^0 + p + \pi^-$ and $K^- + p \rightarrow K^- + \pi + \pi + N$ have been studied systematically over a range of incident momenta from 1.0 to 1.7 BeV/c. The former reaction is dominated by the production of K^* (888 MeV). However, a small but statistically significant enhancement was also observed at 725 MeV, thus substantiating the earlier results from the π -72 experiment. The results of the study of the κ mesons (725 MeV) have been published in Physics Letters.⁴ (See Figs. 1 and 2 for the $\bar{K}^0 \pi^-$ mass distribution.)

The low-momentum transfer events leading to the $\bar{K}^0 p \pi^-$ final state show clear evidence (especially at higher energies) for the one-pion exchange mechanism. Thus, some information on the K - π phase shifts can be obtained. A paper is being prepared on the production mechanism in this reaction.

The reactions $K^- + p \rightarrow \bar{K} + \pi + \pi + N$ show evidence of the Y_0^* (1520-MeV), but no other strong resonances. There is no indication of any $S = -1$, $J^P = 1^+$ meson, with a mass < 1100 MeV, that decays into a K and two π 's. The branching ratio $[K^*(888 \text{ MeV}) \rightarrow \kappa \pi] / [K^*(888 \text{ MeV}) \rightarrow K \pi]$ is found to be less than 0.2%, thus providing some evidence for a 0^+ assignment for the κ meson. The results of the study are being submitted to the Physical Review.

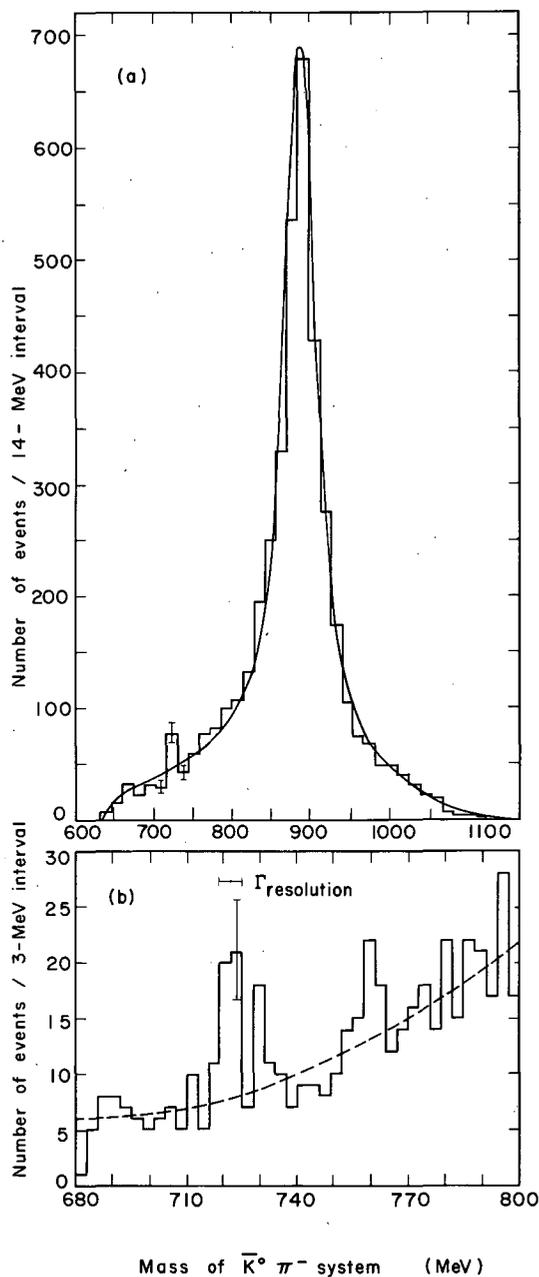
(MHA, GRK, SGW)

$K^- p$ Interactions at 1.050 BeV/c

Work is nearing completion on 65 000 pictures, taken in the 72-inch bubble chamber, of $K^- p$ interactions in the region of the Kerth bump.⁵ The two prongs are being measured on the Spiral Reader and are discussed elsewhere. Other interaction channels have been measured on the Franckenstein. After considerable study and remeasurement of troublesome events, very clean samples have been obtained.

4. S. G. Wojcicki, G. R. Kalbfleisch, and M. H. Alston, Phys. Letters 5, 283 (1963).

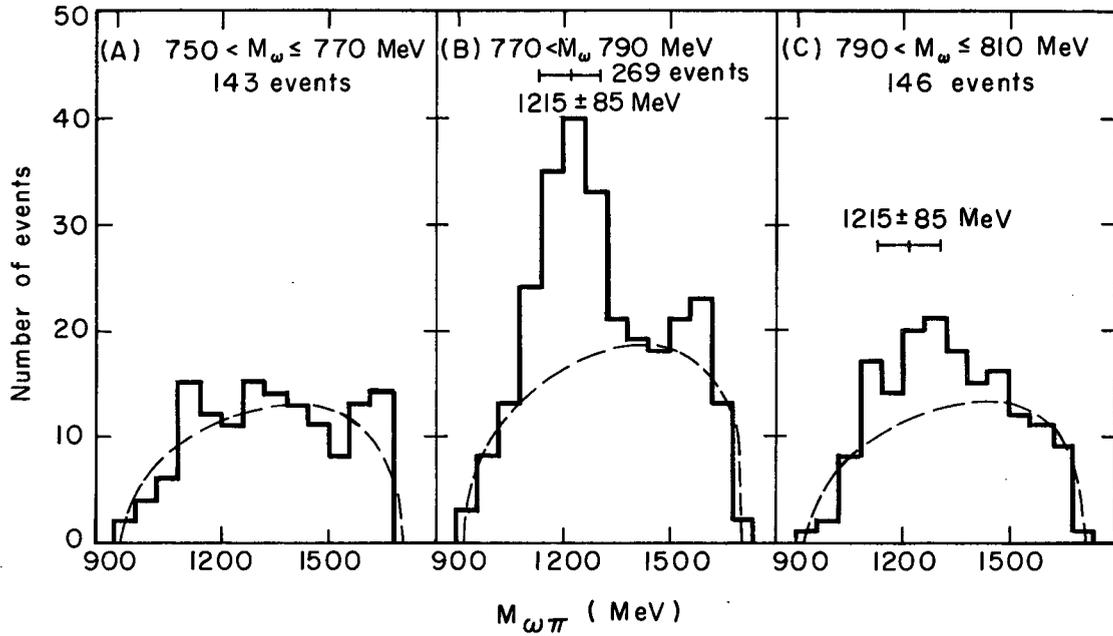
5. O. Chamberlain, K. M. Crowe, D. Keefe, L. T. Kerth, A. Lemonick, Tin Maung, and T. F. Zipf, Phys. Rev. 125, 1696 (1962).



MUB-1771

Fig. 1. (a) Plot of the $\bar{K}^0 \pi^-$ mass of 4296 events from the reaction $K^- + p \rightarrow \bar{K}^0 \pi^- p$ at 1.0 - 1.7 BeV/c. The curve represents the phase space for the reaction proceeding 75% of the time through $K^- p \rightarrow \bar{K}^{*0} p$. The K^* mass is taken as 890 MeV, and its width Γ as 50 MeV. An enhancement is seen at 723 MeV of 33 events above the background curve or 45 (or 42 events above the average of the two neighboring bins).

(b) Plot of the 680 to 800 MeV mass region in 3 MeV intervals to show the structure of the distribution around the κ mass. The dashed curve represents a rough estimate of the background. The resolution is 6 MeV in this region.



MU-32010

Fig. 2. $\omega\pi^-$ Effective-mass distributions from $\pi^-p \rightarrow \pi^+\pi^-\pi^0 + \pi^-p$ events at 3.24 BeV/c, with either neutral three-pion combination having the indicated mass " M_{ω} ."

The two-body channels are of particular interest in attempting to determine the dominant partial waves in this momentum region. The region is marked by strong coupling to the $\bar{K}N$ system. The charge-exchange channel $K^-p \rightarrow \bar{K}^0n$ shows a rapidly changing behavior as a function of momentum, and the differential cross section requires terms through A_5 in the expansion $d\sigma/d\Omega = \sum A_n \cos^n \theta$. The most plausible hypothesis is an interference between even- and odd-parity $J = 5/2$ waves in the $\bar{K}N$ system. Comparison with existing data in the channel $K^-p \rightarrow K^-p$ indicates that these waves are in opposite isotopic-spin channels. On observing a K^-p final-state interaction at comparable energy, Barbaro-Galtieri et al. have proposed a model consistent with these results.⁶

The data in the charge-sigma channels, $K^-p \rightarrow \Sigma^\pm \pi^\mp$, is more confusing. The differential cross section varies more rapidly and requires $\cos^6 \theta$ in one momentum interval. This requires at least some $J = 7/2$ contribution.

The channel $K^-p \rightarrow \Lambda \pi \pi$ proceeds almost entirely through $K^-p \rightarrow Y_1^*(1385 \text{ MeV}) \pi \rightarrow \Lambda \pi \pi$. Since the Y_1^* is known to be a $J = 3/2$ object, in principle an examination of the differential cross section allows a determination of the dominant spin-parity wave of the over-all system. Results are inconclusive at this stage.

Investigation of other channels is continuing.
(DHM, CGW, SGW)

Final-State K^-p Interaction

A study of the $K^- + n \rightarrow K^- + p + \pi^-$ reaction has been completed for K^- of 1.51 BeV/c incident momentum in the 72-inch bubble chamber filled with deuterium. Since no resonances in the $T = 3/2$ $K\pi$ system are indicated by the data, the reaction is a suitable means of investigating the K^-p interaction. In addition to the $Y_0^*(1520 \text{ MeV})$, a K^-p enhancement with a mass of 1765 MeV and a full width $\Gamma = 50 \text{ MeV}$ is observed. This information suggests an interpretation of the K^-p interaction in this mass region (corresponding to an incident K^- momentum of about 1 BeV/c). If the $Y_0^*(1815)$ is a $5/2^+$ resonance, then the $\cos \theta$ terms observed in the K^-p elastic and charge-exchange scattering can be satisfactorily fitted by the hypothesis that the $Y^*(1765 \text{ MeV})$ is a $5/2^-$, $T = 1$ resonance. (See the above paragraphs for a discussion of K^-p scattering at 1.050 BeV/c, or a c.m. energy $\approx 1800 \text{ MeV}$.)

This work has been published in Physics Letters.⁶
(AB-G, AH, RDT)

Investigation of Exchange Mechanisms in $K^-p \rightarrow \Lambda \omega$

More than 4000 events of the type $K^- + p \rightarrow \Lambda + \pi^+ + \pi^- + \pi^0$ were analyzed; the incident momenta varied from 1.2 to 1.8 BeV/c. Background subtraction led to an estimated 2400 events of the type $K^-p \rightarrow \Lambda \omega$. If the reaction were dominated by K exchange, the decay distribution of the normal to the decay

6. A. Barbaro-Galtieri, A. Hussain, and R. D. Tripp, Phys. Letters 6, 296 (1963).

plane should be $\cos^2 \theta$, where θ is the polar angle of the normal to the ω decay plane with respect to the incident K direction, all as viewed in the ω rest frame. If K^* exchange dominates the reaction, then the distribution should be $\sin^2 \theta \times (a + b \cos^2 \phi)$. The direction $-\theta = \pi/2$, $\phi = 0$ specifies the normal to the production plane. The data show the presence of both $\cos^2 \theta$ and $\sin^2 \theta$ but no ϕ dependence. The data also show definite evidence of a term in $\sin \theta \cos \theta \sin \phi$, which, according to Berman and Oakes, cannot come from either K or K^* exchange. Thus, the actual mechanism must be more complicated than K and K^* exchange alone.
(SMF, RWH, DOH, FTS, MLS)

Production of Vector Mesons (Theoretical)

The cross section for the general reaction [pseudoscalar meson + nucleon \rightarrow spin-1/2 baryon + vector meson], and the decay angular distributions for the final particles, have been calculated with the assumption that the reaction is dominated by the exchange of pseudoscalar and vector mesons. The expressions involve five form factors that are functions only of the square of the invariant momentum transfer. These results, along with their application to the reactions $\pi^- + p \rightarrow \Sigma^0 + K^*$, have been reported elsewhere.⁷

The cross section and decay angular distributions for this general reaction have also been obtained for other production mechanisms, including baryon exchanges in various channels. Various terms in the decay angular distributions are found to vanish for some of the simpler production mechanisms. This observation provides a very convenient set of experimental tests for various production mechanisms, and removes the necessity of attempting a complete fit of a given model to the experimental data in order to test that model.

These results are being applied in an analysis of the reaction $K^- + p \rightarrow \Lambda + \omega$. (See the preceding subsection.)
(RWH)

Spin-Parity Analysis by Use of "Moments" [$Y_1^*(1385 \text{ MeV})$]

A program has been developed⁸ to apply the "moment analysis" method of Byers and Fenster⁹ to strong decays, for assumed spins of 5/2, 3/2, and 1/2. Spin is determined from the order of the moments (or the $\langle Y_{LM} \rangle$) obtained from distributions of direction and polarization of decay products; parity is decided by comparison of transverse with longitudinal polarization moments (of the form $\langle \vec{P} \cdot \hat{x} Y_{LM} \rangle$). This method has been utilized to study the $Y_1^*(1385 \text{ MeV})$ observed in ≈ 1000 examples of the reaction $K^- + p \rightarrow \Lambda + \pi^+ + \pi^-$ at incident momentum of 1.22 BeV/c. Identification of the Y_1^* as an $F_{5/2}$ state is excluded; the $D_{5/2}$ assignment is found to be possible though not required. Of the states $P_{3/2}$, $D_{3/2}$, $S_{1/2}$, and $P_{1/2}$, only $P_{3/2}$ is

7. Robert W. Huff, Pseudoscalar and Vector Exchanges in the Production of Vector Mesons, UCRL-11003 (September 1963), to be published in Phys. Rev.
8. J. B. Shafer and J. R. Morris, Spinpar I, Moment Analysis, Alvarez Group Memo P-69, Nov. 1963.
9. N. Byers and S. Fenster, Phys. Rev. Letters 11, 52 (1963).

found acceptable, the excluded hypotheses having confidence levels of the order of 10^{-6} or 10^{-7} . This conclusion strengthens slightly the earlier selection of $P_{3/2}$, based chiefly on two components of the decay Λ 's polarization.¹⁰ The moment analysis of the Y_1^* is being submitted to The Physical Review.¹¹

Another approach to the Y_1^* analysis has been the use of a maximum likelihood function. (DOH) The forms of decay distributions have been constructed for each hypothesis through $J = 5/2$. A search program is carried out to find the best values of moments, i. e., of spherical-harmonic coefficients. The choice of the best spin-parity hypothesis is made by calculating a χ^2 for the fit of the data to the "theoretical" smooth distribution obtained by the likelihood method. The Byers-Fenster analysis yields averages or "projections" of spherical-harmonic coefficients, without detailed a priori knowledge of the distributions; the maximum-likelihood method produces fitted values. Results from the Y_1^* data are remarkably similar as to confidence levels given by the two methods for the spin-parity hypotheses.

A program is now being completed for the Monte-Carlo generation of events with decay and polarization distributions determined by initial-state assumptions. (JBS, JRM) This will permit thorough testing of the above-described methods for any spin-parity hypothesis.

The Byers-Fenster analysis has been developed in a program for analysis of parity-nonconserving decays. This has not yet yielded conclusive results in its use for determination of the Ξ spin.

The Decay $\omega \rightarrow \pi^+ + \pi^- + \gamma$

Investigation has continued on the branching ratio $(\omega \rightarrow \pi^+ \pi^- \gamma) / (\omega \rightarrow \pi^+ \pi^- \pi^0)$ from study of the reaction $K^- + p \rightarrow \Lambda + \pi^+ + \pi^- + \text{neutral}(s)$, with the use of 8049 events at momenta 1.3 to 1.7 BeV/c. Various restrictions were imposed to eliminate events of the types $K^- + p \rightarrow \Lambda + \pi^+ + \pi^-$ and $\rightarrow \Sigma^0 + \pi^+ + \pi^-$. Of the remaining 2717 events, the majority were π^0 (with $\Lambda \pi^+ \pi^-$) events. The spectrum of neutral mass was examined; with a limitation on the error in neutral mass, a peak of 25 events at zero mass was discernible. The background was estimated to be $8\pi^0$ events; thus the number of $\Lambda \pi^+ \pi^- \gamma$ events was concluded to be 17 ± 5 . Comparison with the number of $\Lambda \pi^+ \pi^- \pi^0$ events in the sample indicated a branching ratio of $(\pi^+ \pi^- \gamma / \pi^+ \pi^- \pi^0) = 3 \pm 1\%$ (in which the error is statistical only). These results were reported at the Stanford Conference on Strong Interactions, June 1963. (DOH, JJM, JBS)

Search for T = 2 Resonance

The search for a T = 2 resonance in the $\Sigma - \pi$ system has been finished. The reactions studied were

$$1.5 \text{ and } 1.7 \text{ BeV/c } K^- + p \rightarrow \Sigma^\pm + \pi^\pm + \pi^+ + \pi^- \quad (1)$$

-
10. J. B. Shafer, J. J. Murray, and D. O. Huwe, Phys. Rev. Letters 10, 179 (1963).
 11. Janice B. Shafer and Darrell O. Huwe, Y_1^* (1385-MeV): Study of Spin and Parity by Moment Analysis for $J = 5/2, 3/2, \text{ and } 1/2$, UCRL-11105, (December 1963).

and $1.5 \text{ BeV/c } K^- + d \rightarrow \Sigma^\pm + \pi^\mp + \pi^- + p. \quad (2)$

In hydrogen there were about 1500 events of the correct topology at 1.5 BeV/c and 450 at 1.7 BeV/c. Of these about 1250 and 350 respectively fitted the above reactions. No evidence for a $T=2$ resonance in the doubly charged $\Sigma\pi$ system was observed in the mass spectrum, since the data could be explained by the production and decay of Y_0^* (1405 MeV): Y_0^* (1520 MeV): Y_1^* (1660 MeV); events without Y^* production in the ratio of about 5:2:1:0. In deuterium the number of events studied was about 1700. Of these about 600 could be ascribed to Reaction (2), in which the proton was a spectator and the impulse approximation could be used. The mass distributions of these events could be interpreted as the production and decay of Y_0^* (1405 MeV): Y_0^* (1520 MeV): Y_1^* (1660 MeV): Y_0^* (1815 MeV); events without Y^* production in the ratio of about 2:4:2:1:6. Thus no evidence for a $T=2$ resonance was observed. (MHA, AB-G, AHR, SGW)

K^- -p Elastic Scattering at 1.22 BeV/c (First Experiment Done with SMP)

Approximately 6700 K^- -p two-prong events at 1.22 BeV/c incident K^- momentum have been measured, by using the Scanning and Measuring Projectors (SMP's). The events were analyzed with the PANAL, PACKAGE, LINGO, and DST-EXAM analysis programs. About 1100 rejected events underwent second measurements.

Of the 6700 events measured, approximately 3200 were accepted by the analysis programs as being K^- p elastic scatterings. The angular distribution of these elastic scatterings was then corrected for scanning biases and contamination by π^- incident particles. The corrected distribution was fitted in the c. m. by curves of the form

$$\frac{d\sigma}{d\Omega} = \sum_{n=1}^N A_n \cos^n \theta.$$

Here $n=5$ gave a good fit, but there was a noticeable improvement for $n=6$, and none thereafter. The coefficients are listed in Table I, with the published charge-exchange angular distribution from the same film [1962 CERN conference (MF-L, FTS, MLS)] listed for comparison. (WEH, JM, RR)

K-63 Experiment (72-Inch Chamber)

Beam

A 2.5- to 3.0-BeV/c separated K^- beam has been completed and placed in operation in conjunction with the 72-inch hydrogen bubble chamber. A detailed and still up-to-date description of the design and salient features of the beam may be found in the previous semiannual report.

Exposures to a π^- beam utilizing this same beam equipment were commenced in March 1963; since July 1963, these have been alternated with K^- exposures. A résumé of the π^- exposures is given below under "The π^- -63 Experiment." From July through October, a total of about 150 000 pictures of K^- interactions were made at 2.5 and 2.7 BeV/c.

Table I. A_n coefficients of angular distribution.

	Elastic $n = 5$	Elastic $n = 6$	Charge exchange $n = 6$
A_0	0.29 ± 0.02	0.30 ± 0.02	0.06 ± 0.01
A_1	0.34 ± 0.08	0.19 ± 0.10	-0.34 ± 0.05
A_2	0.12 ± 0.21	-0.40 ± 0.30	0.79 ± 0.17
A_2	-0.52 ± 0.40	0.62 ± 0.61	1.95 ± 0.21
A_4	3.23 ± 0.36	5.6 ± 1.0	-2.17 ± 0.55
A_5	3.76 ± 0.47	2.3 ± 0.78	-1.99 ± 0.21
A_6	---	-2.4 ± 1.0	2.01 ± 0.44
χ^2	25.98	20.08	---
Confidence level	76.5%	93.4%	---
σ_{total}	---	$11.8 \pm 0.3 \text{ mb}^a$	$2.3 \pm 0.1 \text{ mb}$
Over-all normalization uncertainty	$\pm 4.5\%$	$\pm 4.5\%$	---

^a The uncertainty in over-all normalization is not included in the error in σ_{total} .

It has been possible to achieve an average K^- content of about 80% in these pictures. The majority of the remaining 20% of the incoming tracks are pions, but have momenta mostly outside the momentum interval containing kaons. It is hoped that this correlation will permit elimination of π^- -induced reactions, but quantitative evaluation of the extent to which this can be achieved can be determined only after detailed analysis of particular reactions.

To date the average rate of production of K^- film has been approximately equal to the rate of complete first scanning and partial scanning and to the rate of measurement of the more "interesting" topologies.

It is expected that K^- exposures in this beam will continue at least until May 1964, with a total yield of more than 500 000 pictures. (JJM, JBS, FS, JL, DM, AR, DS, AB-G, RDT)

Data Reduction

Approximately 110 rolls (65 000 pictures) of film have been taken at 2.5 BeV/c incident K^- momentum. More than 100 rolls have been obtained at 2.7 BeV/c. (For discussion of the beam and future running, see preceding subsection).

Measurement of all strong-interaction topologies (excluding zero-prong and two-prong events) has proceeded on two of the three SMP devices currently in operation at LRL, plus one conventional Franckenstein machine. Over the past 2.5 months, 20 000 events have been measured on all these machines. Since the anticipated number of measurements in this experiment is approximately 200 000 (based on 200 events per roll on 1000 rolls of film), we expect to finish all first measurements in about 90 weeks, or by mid-1965.

The 7094 programs (in sequence of use)--PANAL, PACKAGE, WRING, AFREET, LINGO, DST-EXAM, and SUMX--are being used to extract pertinent physical quantities from the measurements. At present, approximately 11 hours of computer time per week are required to maintain this program. This figure should gradually increase (about 25%) over the following months to allow for more detailed calculations in the DST-EXAM and SUMX programs.

No physics results can be stated at this time because of the small numbers of events available in the various reaction channels of interest. The final states being studied are of the following types: $YK\bar{K}$, $\Xi K\pi$, $Yn\pi$, and ΞK . Also K^-p scattering will be investigated. (OID, GRK, JL, GAS, and some beam personnel)

The π^- -63 Experiment (72-Inch Chamber)

In a continuing exposure of the 72-inch bubble chamber, the investigation of strange-particle production in π^-p interactions is being extended both in statistical accuracy and momentum range. At lower momenta (1.9 to 2.1 BeV/c), additional data have been accumulated in order to study (a) the production and decay of the κ meson, first observed in the π^- -72 experiment, and (b) the spin and parity of the resonant state at 2190 MeV. All film taken thus far has been scanned and measured; the results are being studied. At

higher momenta (3.2 and 4.2 BeV/c), the general characteristics of the final states are being investigated. In contrast to the observations at lower momenta, the three-body final states arise predominantly through the sequence $\pi^-p \rightarrow K^*Y \rightarrow K\pi Y$. Correspondingly, the four-body final states are produced through decay of double resonances, i. e., $\pi^-p \rightarrow K^*Y^* \rightarrow K\pi Y\pi$. These results suggest the strong role played by peripheral collisions at high momenta.

In addition, 10 000 events of the topology $\pi^-p \rightarrow$ four charged particles were measured. A systematic study of the effective-mass distributions for events fitting the hypothesis $\pi^-p \rightarrow \omega\pi^-p$ showed that a large fraction of the $\omega\pi^-$ systems resulted from the production and decay of a new short-lived meson of mass 1220 MeV and width $\Gamma \approx 180$ MeV. Production and decay correlations as well as decay into other channels (e. g., $K\bar{K}$) are being studied in an effort to determine the spin and parity of this new state. (See Fig. 2 for the $\omega\pi^-$ mass distribution.)

Results of these investigations have been presented in a UCRL report.¹² (SUC, OID, LMH, RIH, GRK, DHM, GAS)

SEARCH FOR DIRAC MONOPOLES IN METEORITES BY USE OF ELECTROMAGNETIC TECHNIQUES

The negative results of the searches for monopoles at CERN and Brookhaven could mean that monopoles do not exist. But even if they exist, they could have escaped production at the accelerators because they are too massive to be made in pairs at 30 BeV. Even if they had been produced in the targets, the magnetic-extraction technique utilized could have failed if the monopoles were bound to nuclei, as they would probably be.

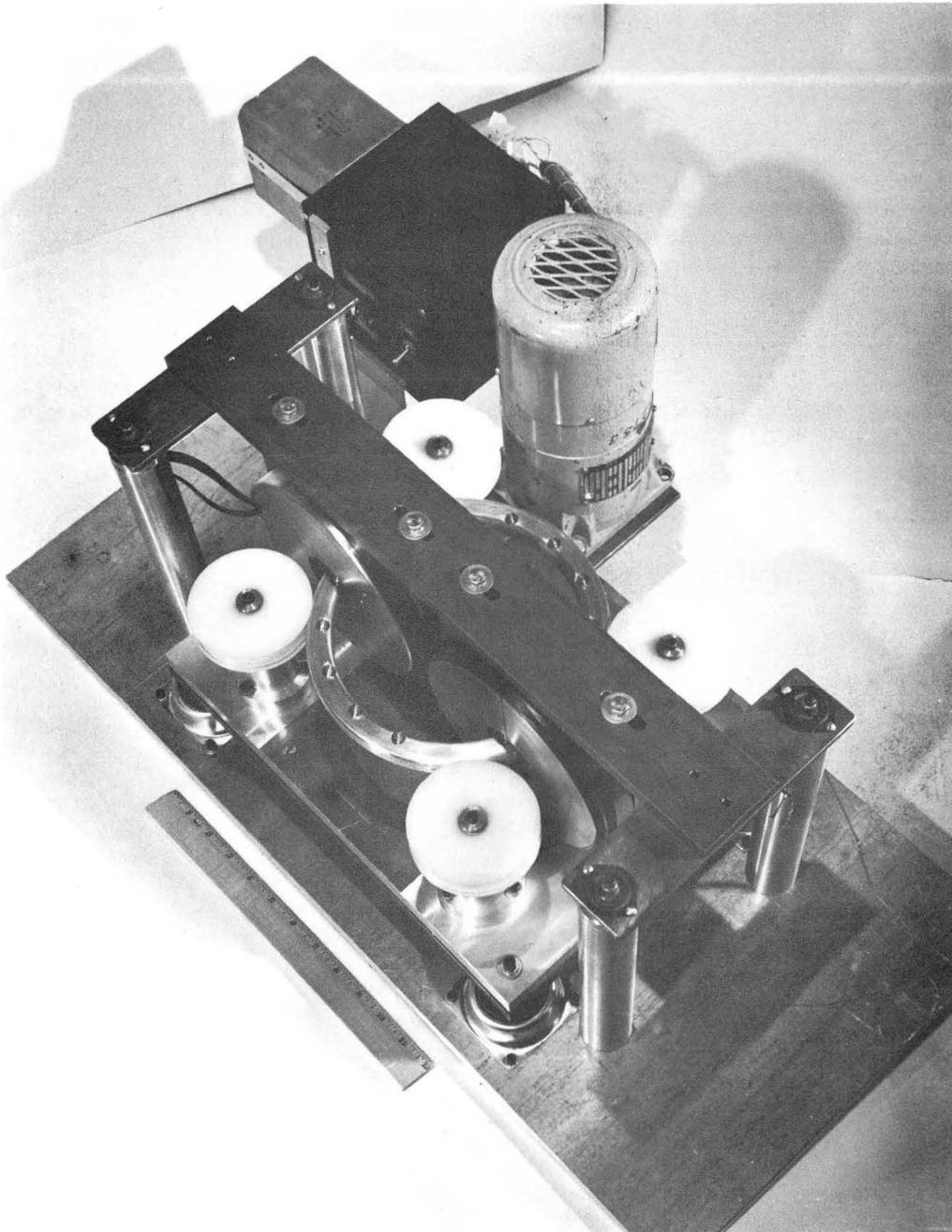
An electromagnetic detector for monopoles has been built and tested. It is based on the concept that a "current of magnetic poles" would be surrounded by an electric field, just as a "current of charges" is surrounded by magnetic field. The "voltage per turn" around a pole current could be measured with a dc voltmeter connected to a coil with N turns.

Figure 3 shows the third version of the monopole detector. The two coils, through which the aluminum ring threads, contain a total of 1.6×10^6 turns of copper wire. The holes in the ring are designed to hold samples of meteoritic iron, as they circulate through the coils at about 50 rps. At that rate, a single monopole will give about 1 μ V of dc signal. The noise in the circuit is about one-tenth of the signal, so one should not be able to miss a pole if it were present in the sample being tested.

Goto, Kolm, and Ford have recently searched for magnetic monopoles in meteorites using the magnetic extraction technique; but in their paper, they say "the field of 53 kilogauss. . . was perhaps not quite sufficient" (to extract the monopoles).¹³ They do not make this reservation about a second

12. J. Kirz, S. U. Chung, O. I. Dahl, R. I. Hess, G. R. Kalbfleisch, D. H. Miller, and G. A. Smith, Production of Multipion States in π^-p Interactions at 3.25 GeV/c, UCRL-11031 (in process).

13. E. Goto, H. H. Kolm, and K. W. Ford, Phys. Rev. 132, 387 (1963).



ZN-4063

Fig. 3. Monopole detector.

experiment in a higher magnetic field. But in a recent preprint, Goto does not refer to the meteorite experiments when he is discussing the limits on the cross section for producing monopole pairs in nucleon-nucleon collisions.

The advantage of electromagnetic detection is that the monopoles can be detected regardless of their binding to nuclei, atoms, or groups of atoms. (LWA, AJS, RGS, RDW)

DATA REDUCTION

Data-Reduction Operations

Personnel (Alvarez Scanning and Measuring Group)

This group began the period (May 1) with 55 full-time equivalents and ended it (Nov. 1) with 61 full-time equivalents. The average was 67.2 FTE's.

Scanning

The following scans were done in the various experiments on 72-inch H₂ bubble chamber film:

<u>Experiment</u>	<u>Scan</u>	<u>Number of Rolls</u>
APE	HiHiPi 1170 MeV/c (π^- in H ₂) four prongs	95
APE	HiHiPi 1170 MeV/c (π^- in H ₂) scatterings	150
APE	Pre-Xmas 1035 MeV/c (π^- in H ₂) scatterings	60
APE	Post-Xmas 1035 MeV/c (π^- in H ₂) scatterings	110
π -72	Rejects scan (π^- in H ₂)	
π -63	First scan 4.2 BeV/c (K^- in H ₂)	97
π -63	First scan 3.2 BeV/c (K^- in H ₂)	179
π -63	First scan 3.15 BeV/c (K^- in H ₂)	
π -63	First scan 2.8 BeV/c (K^- in H ₂)	4
π -63	First scan 2.05 BeV/c (K^- in H ₂)	183
π -63	Cross-section scan (K^- in H ₂)	20
π -63	Second scan	54
K-63	First scan 2.5 BeV/c (K^- in H ₂)	113
K-63	First scan 3.1 BeV/c (K^- in H ₂)	7
K-63	First scan 2.7 BeV/c (K^- in H ₂)	42
K-63	Second scan 2.5 BeV/c (K^- in H ₂)	82
K-72	Second scan 2 prongs 1.11 BeV/c (K^- in H ₂) for Spiral Reader	40
K-72	Third scan 1.22 BeV/c (K^- in H ₂)	43
Total number of rolls scanned		<u>1279</u>

Measuring

During this 6-month period the 15-inch Franckensteins were phased out of the production schedule and the Spiral Reader and SMP's were brought into heavy use. The table below indicates the number of events and hours spent on the various machines.

<u>Measuring projector</u>	<u>Bubble chamber</u>	<u>Hours measured</u>	<u>Number of events</u>
IIA	72 inch	2295	10 143
B	72 inch	2891	18 422
C	72 inch	2305	16 103
D	72 inch	2851	22 459
SR	72 inch	1355	18 819
SMP 1	72 inch	688	2 717
2	72 inch	1635	11 003
4	72 inch	1659	9 755
ID	15 inch	182	825
		<u>Total</u>	<u>15 861</u>
			<u>110 246</u>

The total number of events measured during this period (May 1, 1963 through Oct. 31, 1963) increased 62% over the previous 6 months. As of Nov. 1, 1963, we were measuring at a rate of 3.9 events per calendar hour per machine, or about 270 000 events per year.

The SMP (Scanning and Measuring Projector) SystemGeneral Operations

Following a trial period of SMP operation (completed at the end of April), 7000 two-prong events (from K^-p at 1.22 BeV/c) were measured. This first experiment was begun with two SMP's used 8 hours a day and finished with three SMP's used 16 hours a day. During this time numerous refinements were made in the SMP program. The measurements and first remeasurements for these events took place in May, June, and July. Since then, the three SMP's have been used for measurement of all classes of events in the current Alvarez Group experiments (K-63 and π -63), which amounted to about 17 000 events as of October 31.

Programming Developments

RAIDALL, the program for direct data dialogue between the 709 computer and SMP tables, has been successfully extended to accommodate three SMP tables. After operating with two SMP's, the third was added with no difficulty, and no difficulties in attaching additional machines to the system are foreseen. A major revision of the measuring and sequencing logic in the RAIDALL program has just been completed. This change will provide a convenient structure for accepting corrections to mismeasured tracks without having to remeasure portions of the event that are correct. A number of minor changes have been made in the programs to facilitate measurements and to allow several different experiments to use the SMP system simultaneously.

A program has been written that uses the SMP typewriter to provide a display of SMP measurements resembling the pattern being measured. This program will provide a substitute for the CRT display, which will not be available on the 7040.

The most important current programming projects include further development of error-correction feedback to the SMP operator, simplification of the measuring operations, and conversion of the present 709 programs for use on the 7040 computer. The program for on-line verification of the spatial reconstruction and kinematic fitting of measurements has been under development this summer. So far, there is coding that generates kinematic hypotheses to be tested (based on conservation of charge, strangeness, baryon number, etc.); there is a kinematics test for event configurations of the "V" type; there is a cut-down version of the spatial-reconstruction program PANG; and there are other assorted subroutines that will be required to carry out measurement checks. The most important operational simplification that we will be making to the measurement procedure is the elimination of vertex-point measurements. Presently, vertex points are calculated from short segments measured along tracks originating from the vertex, and later these same tracks are remeasured for their track information. Elimination of these duplicate measurements is nearly equivalent to removing two track measurements from each vertex, and may result in a 20% time saving. The conversion of programs for the 7040 has already begun, and the first program needed (typewriter-test program) is essentially ready for the 7040.

SMP Hardware Developments

The last SMP put into service differs from the previous two in that the electronics has been condensed from three racks to two to provide a more compact arrangement. The present minimum space requirements for one SMP unit are 9 by 9 ft. No notable changes have been made to the electronics except for a minor modification in the track-detector circuitry to make the SMP insensitive to local variations in image light level.

Spiral Reader

During this 6-month period, the spiral reader has been used to measure approximately 12 000 two prong interactions at 1.05 and 1.11 BeV/c. Approximately 16 000 events have been measured (first measurements and first remeasurements of failures). A paper is now in preparation on the angular distribution of the K^- -p elastic scattering in this region.

A certain fraction of time is still being devoted to changes and improvements in the spiral-reader hardware. Some of the changes completed or started during this period are as follows:

1. The memory logic was changed so as to permit a vertex measurement in one periscope sweep, rather than in four or five as before. This saved approximately 20 sec measuring time per vertex.
2. A new crutch-point device has been installed and is in the process of being calibrated. It will enable the operator to measure crutch points while the periscope is in motion.
3. A new fiducial measuring scheme now under development will allow measurement of both fiducials in all three views in a few seconds.
4. New paper-tape-controlled logic is being developed to give a faster operation, as well as greater flexibility in making changes in the measuring sequence.

The programming effort during this 6-month period involved:

1. Modifying the programs to make them compatible with hardware changes,
2. Recoding existing routines to make them more efficient, more flexible and better documented,
3. Modifying the programs as well as writing new routines to handle film from the 81-cm CERN bubble chamber.
4. Starting work on a new and faster tracking method (which will also provide higher reliability for finding tracks), as well as on a better calibration of the spiral-reader optical system,
5. Studying the techniques that would enable one to dispense with the use of crutch points in most cases. The first results look quite optimistic.

The spiral reader is at present beginning to measure the film from the exposure of the 81-cm hydrogen bubble chamber to a stopping antiproton beam at CERN. This is a collaborative experiment with the Padua and Oxford groups.

PEPR (Precision Encoder and Pattern Recognition)

The PEPR device being developed at MIT has been under study by several LRL physicists. (MHA, AHR, FTS) Contributions to the programming effort have been made.

PROGRAMMING EFFORTS

Personnel

The programming work described below has been done by Robert J. Harvey (in charge of the Programming Group), Ben Abington, Margaret Alston, Jim Baldrige, Lynn Champonier, Barbara Cottrell, Orin Dahl, Cecil Draper, Allen Evans, Mark Horovitz, Marge Hutchinson, Daphne Innes, Dave Johnson, Ralph Jones, Norman Larsen, Max Leavitt, Mary Beth Lieberknecht, Jack Merkin, Bart Nyman, Barrie Pardoe, Sam Penny, Jed Rice, Ruby Savala, John Shafer, Jon Stedman, and Tom Tonisson.

General Information

Most of the programs used by the Alvarez Group for the analysis of hydrogen bubble chamber data have been described in previous semiannual reports. The functions of these programs are briefly described: Output from the measuring projectors is passed through PANAL to be checked for obvious errors. PACKAGE reads PANAL output, geometrically reconstructs the measured tracks, and does kinematical fits of the various hypotheses to the events. The output from PACKAGE is reduced by EXAMIN to physically interesting qualities (invariant masses, decay angles, etc). SUMX plots the final data in one- and two-dimensional histograms, scatter plots, etc. Finally LINGO, a library program, keeps records of the events through all stages of the scanning, measuring, and fitting process.

The improvements made to the existing programs, as well as the new programs written during the last 6-month period, are described below. In addition, a lot of effort went into improving the programming for the Spiral Reader and SMP systems and is described with these systems.

Considerable effort has also gone into converting the existing machine language programs (PANAL, PACKAGE, LINGO) to run under the Fortran II monitor on the IBM 7094 and the Fortran IV monitor on the IBM 7040.

PANAL Program

Changes have been made to PANAL¹³ to process data from MATCH,¹⁵ SMP,¹⁴ and the direct magnetic-tape measuring projectors.¹⁶

Two new programs that operate on PANAL output are CHANGE and 1401 SELECT.¹⁷ CHANGE allows the indicative information of events to be changed and the 1401 SELECT uses an IBM 1401 to make a selection of events on serial number and event type.

14. Physics Division Semiannual Report UCRL-10862, May 20, 1963.
15. MATCH—not to be confused with the routine MATCH mentioned in Physics Division Semiannual Report UCRL-10572, though it performs the same function and is described later in this report.
16. Margaret H. Alston, J. Peter Berge, et al., PANAL, Alvarez Physics Note 358 (November 1961, revised February 1963).
17. J. Burkhard, 1401 Select, Alvarez Programming Note P-45 (May 28, 1963).

PACKAGE System

Several routines have been written to facilitate the writing of kinematic-event types.¹⁸ These routines have simpler calling sequences than the standard routines in PACKAGE and, among other things, allow connected vertices to be fitted automatically. Also it is possible to indicate in the output of a given fit the source of the unfitted data, for example, the previous fits in which the tracks have been used.

The three-view-geometry program TVGP is being developed.¹⁴ The part of the program that reconstructs charged tracks with energy loss in an inhomogeneous magnetic field is nearly complete. Simulated input data is reconstructed with acceptable accuracy in a large number of cases, and the cases that fail to be reconstructed are being studied. Methods of compensating for optical aberration and of reconstructing very short and very straight tracks have yet to be programmed. A new kinematics program FIT is also being developed. Routines received from CERN to be incorporated in FIT have been checked and are being modified to use different physical variables.

LINGO Operation

A new production version of LINGO I¹⁹ has been coded for the IBM 7094 to allow the user greater flexibility and to improve the tape-error procedures.

The number of events currently being handled by LINGO I for the various experiments is shown in Table II (all figures are to the nearest 1000 events.)

Table II. Events handled by LINGO I.

Experiment	Events on master lists	Measurements maintained in library	Number of events measured at least once
K-72	189 000	101 000	91 000
KD-72	20 000	4 000	3 000
π -63	34 000	23 000	17 000
K-63	61 000	18 000	17 000
Total	304 000	146 000	128 000

Specifications for future library systems using large capacity storage devices are being studied.

18. Orin I. Dahl, New Subroutines for Coding PACKAGE Event-Types, Alvarez Programming Note P-49 (June 18, 1963).
19. Samuel Penny, LINGO System, Alvarez Programming Note P-7, (January 4, 1962), and operating instruction for LINGO I, Alvarez Programming Note P-8, (September 11, 1962).

SUMX Program

The new input-output system has now been incorporated in SUMX.²⁰ It is buffered more efficiently, automatically assigns scratch tapes, and is compatible with Fortran II input-output routines.

GENIE System

WRING²¹ has been adapted to save additional quantities of interest to the physicists.

The GENIE system²¹ as now used in the π -63 and K-63 experiments²² is both event-type and experiment independent. To achieve this independence, sufficient information is passed along from program to program.

PHASE SPACE Programs

Further additions and modification have been added to this set of programs.^{23, 24}

MATCH Program

The purpose of MATCH is to group the image tracks (one track from each view of a preselected vertex) so that each group comprises images of the same bubble chamber track. Stereo-reconstruction of the bubble chamber tracks is possible only when this grouping is complete.

Tests are applied to each pair of images (each track in View 1 is paired with each track in Views 2 and 3, and each track in View 2 is paired with each track in View 3). When a pair fails one of the tests, other pairings can sometimes be excluded, which results eventually in the unique grouping of the (image) tracks. This depends however, on the tests' being sufficient.

Allowance is made for the different magnification between views, and each track image is approximated by a segment of a circle.

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20. Lynn J. Champomier, SUMX, Alvarez Physics Note 389 (June 21, 1962).
 21. D. Johnson, WRING and GENIE, Alvarez Programming Note P-5 (revised August 12, 1963).
 22. Orin I. Dahl and George R. Kalbfleisch, π 63-K63-SMP Data Analysis System, Alvarez Programming Note P-54 (July 25, 1963).
 23. Markus Horovitz, A Summary of Available Programs for Calculating PHASE-SPACE Distributions, Alvarez Physics Note 392 (May 23, 1963).
 24. Barbara Cottrell and Markus Horovitz, Kinematics Archives, Alvarez Programming Note P-53 (July 18, 1963).

The restrictions currently being applied are:

- a. The slopes at the beginning of the tracks, relative to the stereo axis, should both be in the first two or last two quadrants;
- b. Reconstruction of the track should give an end point within the illuminated volume of the chamber;
- c. In both views the maximum distances between the track and the line parallel to the stereo axis passing through the vertex should be equal;
- d. The curvatures of the track in both views should have the same sign. Depending on the measuring machine used, MATCH at present achieves 90 to 95% efficiency.

Miscellaneous Programs

CONFLICT has been written to check the scanning of bubble chamber film by comparing the scanning information from separate scans of the same event.²⁵

The input-output routines used by PANAL, PACKAGE, CONFLICT, and LINGO have been coded in FAP and made compatible with Fortran II input-output routines.

A program ALAC has been written for the time accounting of Alvarez Group computer usage.²⁶

Some routines have been written for extending the use of the CRT on the IBM 7094.²⁷

Film from CERN is being analyzed with the Alvarez Group Programs, and changes have had to be made to PANAL and PACKAGE because of the difference in bubble chamber design. Because the measuring procedure for the CERN film differs from that of the Alvarez 72-inch film, MATCH has had to be written to associate the images of a given track in all three views with each other.

Work Done for Other Groups

Markus Horovitz and Grove Nooney have cooperatively written UNFOLD for numerically inverting convolution operators.²⁸ This work was for Aldo Rescigno of Donner Laboratory of Biophysics and Medical Physics.

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25. Jack Merkin, Preliminary description of CONFLICT, Alvarez Programming Note P-30 (February 11, 1963).
 26. Marjorie S. Hutchinson, ALAC-Alvarez Group Time Accounting Program, Alvarez Programming Note P-30 (February 11, 1963).
 27. James H. Burkhard, Greek Letter Plotting Subroutines, Alvarez Programming Note P-38 (April 16, 1963) and APETV, Alvarez Programming Note P-43 (May 10, 1963).
 28. Markus Horovitz and Grove Nooney, UNFOLD - A computer Program for Analyzing Linear Systems by Calculation in the Time Domain, UCRL-10927 (July 1963).

A decision method has been devised to test whether tracer experiments on systems of biochemical reactions provide evidence of compartmentation in cells. It is suggested that in the environment of a cell there are several subenvironments or compartments in which certain of the cellular reactions always occur. Preliminary analysis shows that the total system is under-determined by the measurements. The compartmentation hypothesis has been proven on a small subsystem. The work is being done by Markus Horovitz in cooperation with Grove Nooney for V. Moses of the Bio-Organic Chemistry group.

BUBBLE CHAMBER OPERATION AND DEVELOPMENT

72-Inch Bubble Chamber Operations

This report period began with the 72-inch chambers being operated for the Trilling-Goldhaber and Powell-Birge groups. Their experiments continued intermittently until the end of June, and during May and June they obtained about 300 rolls of film (or 1.8×10^5 pictures). The chamber operated well except during a 9-day shutdown to repair a vacuum leak.

July was a poor month because of 2 weeks' stand-by operation and poor production for the remaining weeks. Donald Miller et al. obtained 100 rolls of film on the π -63 experiment; and Joseph J. Murray et al. obtained 7 rolls on K-63.

The period August through October was spent in a great deal of stand-by and inefficiency from the standpoint of film production. Miller and Murray each obtained 220 rolls during the 3 months. During this period, the chamber was ready to go essentially 100% of the time and was not the cause of any lost production.

During the report period the 72-inch crew members worked on the 25-inch chamber and the completion and testing of the spectrometer system.

25-Inch Bubble Chamber Development

The magnet assembly was completed and successfully tested to 23 kG. Field plots were made by the Magnet Measurements Group.

The chamber was assembled for expansion and pressure tests with dummy plates in place of the window. The complete unit was pressure checked and the expansion system tested with the chamber at room temperature. The chamber was then assembled with the glass in place, and cool-down for the engineering test commenced at the end of October.

The chamber was filled with liquid hydrogen and the first tracks were observed in the first week of November. Initial tests were run with a light delay of 600 μ sec, and the chamber was made quite sensitive.

Multiple pulsing of the chamber has been accomplished; at present double or triple expansions approximately 250 msec apart can be made during each Bevatron cycle.

During the engineering run various operating conditions will be investigated.

PHYSICS RESEARCH

Walter H. Barkas in charge

STRANGE-PARTICLE RESEARCH

K⁺-Meson Decay

Douglas Greiner, W. Z. Osborne, Frances M. Smith, and Walter H. Barkas

In order to study some outstanding questions in K⁻-meson decay, a large (13 liter) stack of emulsion was exposed to a beam of K⁺ mesons, some 2×10^6 of which stopped in a limited volume of the stack. The exposure and stack were designed so that all K⁺ decay products lying within a restricted cone could be brought to rest in the stack. Prior to this, a smaller stack of 0.4 liter was exposed to test the beam. Some preliminary results were obtained from the small stack: The τ'/τ ratio was measured as 0.32 ± 0.03 and the energy spectrum of 71 τ' decays was obtained. The Q values of some 40 τ mesons were measured.

A systematic study of the large stack has begun--the contemplated program will take 2 to 3 years to finish. We plan to identify completely some 1000 unbiased decays, and to measure the Q values of the τ , $K_{\pi 2}$, and $K_{\mu 2}$ decays to higher accuracy than has been done heretofore. To date, the ranges of eight $K_{\mu 2}$ secondaries and six $K_{\pi 2}$ secondaries have been measured. Much further work on these ranges and on the minor decay modes is planned.

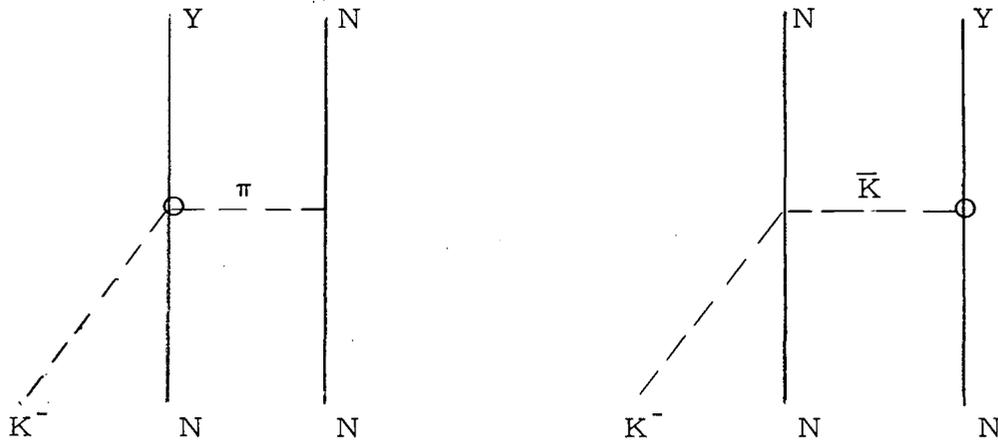
K⁻-Meson Interactions with Complex Nuclei

W. Z. Osborne, Jack W. Patrick, Frances M. Smith, and Walter H. Barkas

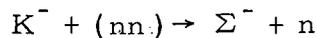
In emulsion the reactions of K⁻ mesons with nuclei proceed through many channels, with a corresponding abundance of observable processes; some, however, require very detailed analysis.

Previously an unbiased sample of some 300 events, in which pions were produced but no charged strange particles were emitted, had been partially studied by making range measurements on the pions. In this report period, the remaining part of this work consisted largely of energy measurements on tracks of particles that interacted in flight or escaped from the stack. This study has shown that the negative pions are found in two energy groups corresponding to associated Σ and Λ production, whereas the positive pions are found only in the group characteristic of Σ hyperon production.

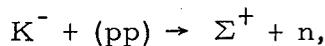
Another type of event is one in which a real pion is not produced in the reaction. The reaction $K^- + (np) \rightarrow \Sigma^- + p$ has been studied. Some 48 such events with $T_{\Sigma} \geq 60$ MeV, and $T_p \geq 30$ MeV were identified. In these, the distribution of the Σ -p invariant mass exhibits no prominent features in the interval 2140 to 2360 MeV, and no evidence of a resonance has been found. The main features of nonmesic K⁻ interactions appear to be consistent with the following basic diagrams;



We have one observation apparently contradicting results of other laboratories. The reaction



is thought to be rare compared with



because others have observed one-prong K^- stars in which the only prong is a Σ^+ hyperon of kinetic energy greater than 60 MeV, but they have not observed similar stars in which the prong was a Σ^- . We, on the other hand, have found three such Σ^- stars and no clear-cut example of a Σ^+ star.

Further work is being done on the total $\Sigma\pi$ momentum spectrum [Fig. 2b of Physics Letters 5, 66 (1963)] from stars produced by capture in C^{12} in which the Σ , the pion, and the recoil nucleus are the only visible products. The problem is the correction of the low-momentum spectrum of the $\Sigma\pi$ system. When this momentum is small, the recoil is not seen even if it is B^{11} .

In the previous analysis correction was attempted for such events, but a better estimate of the contamination of O^{16} captures is now being made.

Mechanisms of Hyperfragment Production

Jack W. Patrick

A sample of 65 parent stars of hyperfragments has been studied, along with the hyperfragments, in an attempt to understand the mechanism of hyperfragment production. The stars selected emitted either a meson, a fast proton, or both. At least 20% of all hyperfragment parent stars fall in this category.

Several criteria were used to separate K captures in light nuclei, CNO, from those in heavy nuclei, AgBr. These criteria were: the presence of Auger electrons, the range of the shortest prong from the parent K⁻ star, and the number of prongs in the parent stars.

Hyperfragments are emitted preferentially opposite to the direction of emission of associated pions or fast protons. If we call this the backward direction B, then the ratio of backward pions or fast protons to forward (F) pions or fast protons—i. e., parallel to the hyperfragment—becomes B/F = 31/13 for pions and B/F = 25/7 for fast protons. Nine events have both a pion and a fast proton and one event has two fast protons.

The distribution of pions from the parent stars is such as to allow a division into two groups. The first, and much the larger, group of pions is of low energy (20 to 90 MeV), and is presumably associated mostly with Σ production and subsequent absorption (indirect Λ production). The second and smaller group consisting solely of negative pions is undoubtedly associated with direct Λ production. We conclude that a majority ($\approx 70\%$) of hyperfragments are produced in indirect Λ production (Σ conversion).

SPACE RESEARCH

Geomagnetically Trapped Protons in the South Atlantic Anomaly

Harry H. Heckman

(With G. H. Nakano, Lockheed Aircraft Corporation, Missiles and Space Company, Palo Alto Facilities, California.)

In late June 1963, our first emulsion package containing electron-sensitive emulsion was recovered in good condition from an oriented, 4-day polar-orbiting satellite. We are now completing measurements on the energy spectrum of protons $58 < E < 600$ MeV. These protons were detected at 400 km altitude in the South Atlantic magnetic anomaly where the inner Van Allen belt reaches its lowest altitude. As deduced from the spatial orientation of the mirroring plane of protons, the mean L value at 400 km altitude in this region is 1.40 ± 0.03 . Preliminary results show that from 58 MeV to about 100 MeV, the omnidirectional differential-energy spectrum is approximately constant. Between 100 and 150 MeV the spectrum decreases and approaches $N(E) \propto E^{-4.2}$ for $E > 150$ MeV.

In addition to measuring the above spectrum, we are continuing to monitor the absolute proton flux between 58 and 69 MeV, the scale height of the atmosphere (obtained from the east-west asymmetry of the proton flux), and the geographic location of the mirroring region of the protons. These spatial and temporal studies are being carried out with six emulsion packages (selected from a total of twelve recoveries) orbited during the 12-month period beginning September 1962. Analysis of these data is about 60% complete. No significant temporal variations in any of the quantities has been observed to date.

HEAVY-ION RESEARCH

Neutrons Produced from Heavy-Ion Reactions

William G. Simon

Calculations were made of the ratio of the fission to neutron width Γ_n/Γ_f for the compound nucleus resulting from the bombardment of Au^{197} by O^{16} . In making these calculations, we use the recent (not yet published) results of Cohen, Swiatecki, and Plasil for the fission barrier. The resulting values of Γ_n/Γ_f support our conclusion (arrived at by examining the experimental angular distribution of neutrons) that neither fission nor neutron emission dominates the de-excitation process of this compound system.

Charged-Particle Production in Heavy-Ion Reactions

Donald V. Reames

In an effort to explain the spectra of charged particles produced in heavy-ion interactions, we have undertaken to calculate the theoretical spectra based on the statistical model including the effects of both angular momentum and multiple emission. Early results show not only that the competition among decay modes can be substantially affected by angular momentum, but also that the effects can be changed with successive evaporations, depending on the amount of angular momentum removed in the preceding stages. It is hoped that this quantitative evaluation of the particle spectra (with moments of inertia calculated from the liquid-drop model) can also be used as a test of the consistency of this model with the observed particle spectra.

MISCELLANEOUS CALCULATIONS AND MEASUREMENTS

Stopping-Power Calculations and Measurements

Walter H. Barkas

As part of the work of the Committee on Nuclear Science of the National Research Council, extensive calculations have been made for a report on stopping powers of virtually all materials and the ranges of various charged particles in them. This report is being done in collaboration with Dr. Martin Berger of the National Bureau of Standards.

In addition, an experimental study is being prepared of the stopping-power difference, as a function of atomic number, for positive and negative particles of the same velocity.

Scattering of Stopping Protons

William G. Simon

We have measured parameters describing the shape of stopping proton tracks in nuclear emulsion. These results were found to agree with those calculated by Barkas.¹ For the scattering factor K_0 , we obtain the value

$0.105 \pm 0.005 \text{ (MeV}/\mu)^{1/2}$. We calculated this quantity using Molière's theory with a cutoff angle of 4° , and obtained the value $K_0 = 0.117$. The results of these measurements were used to obtain escape probabilities for protons originating from n-p collisions within an emulsion layer. A knowledge of these escape probabilities is required in the use of nuclear emulsions for neutron spectroscopy.

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1. W. H. Barkas, Nuclear Research Emulsions (Academic Press, New York, 1963) p. 432.

PHYSICS RESEARCH

Kenneth M. Crowe in charge

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

THEORETICAL GROUP

David L. Judd

THEORY OF THE SCATTERING MATRIX

The analyticity properties of the scattering matrix for processes involving arbitrary numbers of particles are being studied. The objective is to reformulate the postulate of maximal analyticity so that it is easier to apply and also follows more directly from the physical principle that the analytic structure of the S matrix be such that all its singularities are determined by its other general properties. The role of unitarity in the determination of the analytic structure has been shown to be unimportant. It is rather the superposition principle and the fact that S transforms "in" to "out" that leads to the important discontinuity equations, upon which the analytic structure is based. (Henry P. Stapp)

The precise content of the principle of maximal analyticity has been explored by means of a sample problem on production amplitudes. Singularities obtained by a first-order iteration of the discontinuity equation were considered. The physical sheet was determined by a requirement on the homotopic property of the path of continuation that connects physical regions of crossed processes. Single-variable discontinuity equations were derived by the method of analytic continuation. A paper on this work is now in preparation. (Rudolph C. Hwa)

Work is continuing on the cluster decomposition properties of the S matrix, i. e., those requirements on the structure of the S matrix that must be satisfied if it is to be physically meaningful. A fundamental result has been that, if the S matrix is parametrized in terms of so-called cluster amplitudes, the physical requirement that interactions be roughly local has the consequence that any cluster amplitude be free of delta functions that conserve four-momentum among a subset of particles taking part in a process described by that amplitude.¹ Thus the cluster amplitude corresponds to the sum of all connected Feynman diagrams in perturbation theory. Consequently the unitarity relations may be written completely in terms of connected parts, as was pointed out by Stapp.² Currently we are investigating the relationship between free-particle poles and the unitarity condition. (Eyvind H. Wichmann and James H. Crichton)

Studies have been made to obtain an integral representation for production amplitudes. Discontinuities of the scattering function are determined by repeated iteration of the discontinuity equations. For a box diagram, a triple-integral representation is obtained with complex contours due to the inevitable emergence of complex singularities. By placing

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1. E. H. Wichmann and J. H. Crichton, Cluster Decomposition Properties of the S Matrix (UCRL-10860, June 1963)(Phys. Rev. to be published Dec. 1963).
 2. H. P. Stapp, The Decomposition of the S Matrix and the Connection Between Spin and Statistics, UCRL-10289 June 1962.

the branch cuts along their "natural" positions, a conformal transformation can be made to yield an integral representation that has only real contours. This work is now completed and will be summarized in a report to be prepared. (Rudolph C. Hwa)

The asymptotic behavior of a partial-wave amplitude of a two-body scattering process as a function of the energy was determined under the following assumptions: (a) The total scattering amplitude satisfies the Mandelstam representation, and (b) its asymptotic behavior is of the Regge-pole type.³ It has been found that a partial-wave amplitude behaves as $E^{\alpha(0)-1}$, where $\alpha(0)$ is the position of the leading Regge pole at zero total energy. Combined with the relation $\alpha(0) < 1$ derived by Froissart;⁴ this result leads to the following consequences:

1. The asymptotic behavior of partial-wave amplitudes is determined by $\alpha(0)$ and not by the spin of the exchanged particles. This removes an old difficulty in the Chew-Mandelstam bootstrap program.
2. The nearest singularity technique is justified.
3. All partial-wave dispersion relations can be written without subtraction for physical values of the angular momentum. This proves that there is no arbitrary parameter in the Chew-Mandelstam theory.
4. In a partial-wave dispersion relation, two cuts at $l = \alpha(0) - 1$ contribute to the amplitude functions of angular momentum but their sum does not have that cut. This is the first clear-cut example of a mutual cancellation of angular momentum cuts. This work has been submitted to the Physical Review.⁵ (Roland Omnes)

A branch point in the partial-wave amplitude, at the highest value of the energy attained by the boundary of the third double-spectral function, has been investigated. The discontinuity across this cut has two terms for general l ; (a) one has a pole at negative integral l values and vanishes at physical l values, (b) the other is finite and present for physical l values. The fact that the second term, and hence the singularity, survives for physical l has been a source of some confusion in the literature. The first term has been studied by Gribov and Pomeranchuk and gives rise to the essential singularities at negative integral l values. This work (C. Edward Jones and Vigdor L. Teplitz, Singularities of Partial-Wave Amplitudes Arising from the Third Double Spectral Function, UCRL-10989, Aug. 1963), is to appear in Nuovo Cimento. (Vigdor L. Teplitz and C. Edward Jones)

3. G. F. Chew and S. C. Frautschi, Phys. Rev. Letters 7, 396 (1961).

4. M. Froissart, Phys. Rev. 123, 1053 (1961).

5. R. Omnes, Asymptotic Behavior of Partial-Wave Amplitudes, (UCRL-11008, Aug. 1963) submitted to Phys. Rev.

An investigation of essential singularities in complex angular momentum of the spinless two-body scattering amplitude at negative integer values of angular momentum and large negative energy for certain nonlocal potentials⁶ is being extended to the case of scattering of two particles of spin 1/2 in the presence of a spin-dependent potential. (John Hutchins)

The properties of the Bethe-Salpeter equation are being investigated from a formal mathematical point of view. For a ϕ^3 scalar field theory, the equation can be transformed into an integral equation with an L^2 kernel and then all the standard mathematical theorems apply; in particular the kernel has only a discrete spectrum. For other theories this is not the case and there exists a continuous spectrum. Presumably the existence of a continuous spectrum implies the existence of cuts in the angular momentum plane. For theories in which a discrete spectrum exists, there is the possibility that self-consistent bootstrap solutions exist. We hope to find such solutions. Further work will be done on modifying the potentials by including wave functions. (Michael Scadron and Jon A. Wright)

We have written the Fadeev equations,⁷ which express the three-body scattering amplitude in terms of two-body scattering amplitudes, using for the set of complete states a new set in which the quantum numbers are the three energies of the particles in their c. m. system and the total angular momentum. The resulting equations are much simpler than those obtained up to now in the three-body problem.^{7, 8, 9} They open a possibility of discussing practically for the first time the overlapping resonances or the three-body resonances. They are also well suited for discussions of the analyticity of three-body scattering amplitudes as a function of total angular momentum which up to now has not been treated satisfactorily. This work is continuing. (Roland Omnes)

A study of the theory of temporarily correlated measurements is being made in collaboration with Marvin L. Goldberger. An example would be the observation of the autocorrelation function for a particle counter in a scattering experiment. The study involves an extension of the theory of measurement and an analysis of the physical significance of correlations in quantum mechanical systems. (Kenneth M. Watson)

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6. J. V. Lepore and R. J. Riddell, Jr., Phys. Rev. Letters 10, 550 (1963).
 7. L. D. Fadeev, Zh. Eksperim. i Teor. Fiz. 39, 1459 (1960), Soviet Phys. JETP (English Transl) 12, 1014 (1961).
 8. C. Lovelace, Edinburgh University Preprint - Three Particle Systems and Unstable Particles.
 9. S. Weinberg, UC Berkeley Preprint - On the Systematic Solution of Multiparticle Scattering Problems.

x-Ray analysis of crystal structure gives the modulus, but not the phase, of the scattering amplitude. Using the fact that the scattering amplitude is an analytic function, we are attempting to determine the phase using a dispersion relation. (Harvey Gould)

PARTICLE PHYSICS AT HIGH ENERGIES

A detailed study of the dynamical S-matrix equations originally proposed by Chew¹⁰ and further developed by Chew and Jones¹¹ has been made. An exact version of the dynamical equations has been formulated and an investigation made of the existence and nature of the solutions. It has been established that even in the exact problem the equations can be converted to standard-type, soluble integral equations. Some investigations of various aspects of the strip approximation, including a study of the validity of the crossing symmetric Regge representation, have also been made. (C. Edward Jones)

A detailed set of new strip-approximation equations for strong interactions has been formulated, based on a combination of the N/D method and superposition of top-ranking Regge poles in all three of the two-body reactions connected by analytic continuation. Only real values of angular momentum less than 1 need be considered in the bootstrap calculation. It is hoped that in this case the Pomeranchuk and ρ trajectories can be calculated in terms of a single parameter. (Geoffrey F. Chew and C. Edward Jones)

Numerical solutions to the strip-approximation equations for $\pi\pi$ scattering of Chew, and Chew and Jones are being obtained on the IBM 7094. Assuming the form of Regge trajectories in the crossed channels, we find that the kernel and inhomogeneous terms of an integral equation for the partial-wave amplitudes will be obtained using a computer program that is nearly complete. The integral equation must then be solved. (Geoffrey F. Chew, Donald Chaffee, and Vigdor L. Teplitz)

The results of a previous calculation of the Pomeranchuk trajectory have been used to fit the existing pion-nucleon diffraction-scattering data. By using our previous calculation of the Pomeranchuk trajectory¹² together with the second vacuum trajectory, it was shown that the existing data are consistent with the predictions of the Regge pole hypothesis. This work has been published.¹³ (Akbar Ahmadzadeh and Ismail A. Sakmar)

10. G. F. Chew, Phys. Rev. 129, 2363 (1963).

11. G. F. Chew and C. E. Jones, A New Form of Strip Approximation, UCRL-10992 Aug. 1963.

12. A. Ahmadzadeh and I. A. Sakmar, Phys. Letters 5, 145 (1963).

13. A. Ahmadzadeh and I. A. Sakmar, Phys. Rev. Letters 11, 439 (1963).

A phenomenological treatment of the ρ trajectory has been carried out.¹⁴ Because the experimental information utilized in this problem was not sufficient to determine the solution uniquely, several possible solutions were given, together with plausibility arguments as to which solution is more likely. (Akbar Ahmadzadeh and Ismail A. Sakmar)

A dynamical N/D model is used to correlate the leading Regge poles corresponding to different strengths of interaction at a given energy. In the nonrelativistic problem this method proves to be particularly accurate for the location of the Regge trajectory. In the relativistic case it is used to calculate the ρ -meson Regge pole at zero energy, on the basis of the present knowledge of the Pomeranchuk Regge pole and of certain aspects of the dynamics of the $\pi\pi$ system. (Report titled " ρ -Meson Regge Pole at Zero Energy" submitted for meeting of the American Physical Society, Pasadena, December 19-21, 1963). (Alberto Pignotti)

An improved calculation is being attempted for the amplitude of nucleon-antinucleon annihilation into two pions within the Mandelstam framework. Kinematic and crossing relations have been studied and the N/D equations derived, with contributions from important poles and resonances in different channels taken into account. Scattering in the crossed π -N channels is used as input information in order to carry out the necessary analytic continuation. Numerical data for π N scattering are now being put into the crossing and dispersion relations in order to obtain the annihilation amplitude. These results will be used in the future for the N-N problem. (Kwok M. Ong and Malcolm Mac Gregor)

In N/D calculations,¹⁵ there are cases in which the integral equations for the Jost D function are not of the Fredholm type. This appears particularly for f/f equations¹⁶ and for the new strip-approximation equations investigated by Chew and Jones.¹¹ It had been shown by Omnes for f/f equations¹⁷ and by Chew for the strip-approximation equations¹⁸ that the main singularity could in principle be removed by use of the Wiener-Hopf technique to lead to a Fredholm equation. It has been discovered, in fact, that this Wiener-Hopf technique could be made practical and that the resolvent kernel of the corresponding integral equation could be calculated analytically and was fairly simple. We have applied this method to the two above examples. A paper on this work is being written. (C. Edward Jones and Roland Omnes)

The Khuri series for the scattering amplitude has been modified in such a way as to single out the Born term. General arguments have been given to show that this modified series converges considerably faster than

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14. A. Ahmadzadeh and I. A. Sakmar, A Phenomenological Treatment of the ρ Trajectory, (UCRL-11032 September 1963), submitted to Phys. Rev.
 15. G. F. Chew and S. Mandelstam, Phys. Rev. 119, 467 (1960).
 16. R. Omnes, Nuovo Cimento 21, 526 (1961).
 17. R. Omnes, The Singularity of the f/f Equations, Rapport C. E. A. No. 3058, 1961.
 18. Geoffrey F. Chew, The Artificial Singularity in the N/D Equations of the New Strip Approximation, (Dec. 1962) (unpublished).

the original series. By integration of the Schrödinger equation with a single Yukawa potential, the partial-wave amplitude and the Regge parameters were calculated, and the results were used to test the practical convergence of the Khuri series. It was shown that in practice the modified series is considerably superior to the original series. This work has been submitted for publication.¹⁹ (Akbar Ahmadzadeh)

A general study is being undertaken of the problem of Regge trajectories in fermion channels. The program now is concentrated on putting the results of Gribov on a more rigorous basis and on investigation of the possibility, unique to fermion channels, that trajectories of opposite parity are dynamically dependent. It is hoped that eventually numerical calculations can be carried out. (Geoffrey F. Chew and John Stack)

An experimental test has been proposed for the presence of Regge cuts in the crossed channel of boson-baryon scattering processes. The test depends on the difference in behavior toward the forward direction of the interference of a pole and a cut from that of two poles. This work was published in *Physics Letters* 6, 73 (1963). (Vigdor L. Teplitz and Keiji Igi)

A critical analysis of the current situation in the theory of nucleon-nucleon scattering is being undertaken, with the aim of clarifying the role played by the so-called resonance and continuum contributions to the scattering amplitude. It is hoped to improve and refine the earlier calculations²⁰ on this problem. (Richard A. Arndt, Elliot Leader, and Malcolm MacGregor)

The derivation of numerical results from the theory of nucleon-Compton scattering²¹ is in progress, and definitive results are expected soon and will be submitted to *The Physical Review*. It is hoped that some information about the $\pi\pi$ S-wave-isotopic-spin-zero interaction will be obtained from this analysis, and that it will be possible to get reasonable agreement between theory and experiment in γn scattering. (Elliot Leader)

High-energy πp , pp , and $\bar{p}p$ cross sections measured at Brookhaven are being used to determine Regge pole parameters in collaboration with William Rarita. A good fit has been obtained for πp on the basis of two trajectories, P and P' , with an ambiguity in the amount of polarization present. The pp and $\bar{p}p$ cross sections are being studied on the basis of three trajectories— P , P' , and ω —and the further assumption of the absence of spin-flip terms. A satisfactory fit to both cross sections simultaneously has not yet been obtained. (Vigdor L. Teplitz)

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19. Akbar Ahmadzadeh, A Modified Khuri Series and Its Convergence for a Single Yukawa Potential, UCRL-10929, July 1963, submitted to *Phys. Rev.*
 20. D. Amati, E. Leader, and B. Vitale, Theory of Nucleon-Nucleon Scattering. IV, *Phys. Rev.* 130, 750 (1963).
 21. A. C. Hearn and E. Leader, Fixed Angle Dispersion Relations for Nucleon Compton Scattering, *Phys. Rev.* 126, 789 (1962).

The problem of the scattering of two pseudoscalar mesons belonging to the octet representation of $SU(3)$ is studied in the approximation of considering the forces due to the exchanges of the f^0 resonance and the known family of vector mesons. Within this model it is concluded that even-signature trajectories for a singlet and an octet should exist, the latter coinciding in position with the one associated with the octet of vector mesons. This coincidence is removed, however, if the even-signature octet exchange is introduced. A calculation of this splitting is proposed. The singlet even state is naturally associated with the Pomeranchuk trajectory and the isospin zero component of the octet with the second vacuum trajectory. (Alberto Pignotti)

The possibility that the vector resonances have the symmetry of the adjoint representation of $SU(4)$ has been investigated. This assignment is motivated by the possibility that the κ resonance has spin and parity $(1, -)$ and leads to the prediction of a new resonance (λ) in either the two-pion or three-pion channel. The assumption of mass splitting interaction of the Gell-Mann Okubo type leads to two independent mass formulas, one predicting the mass of the λ (870 to 950 MeV), the other providing a check of the assumption on the basis of the known masses (valid to $\pm 11\%$). The third quantum number (z) present in $SU(4)$, in addition to the Y and T_3 present in $SU(3)$, is not conserved in the production and decay of κ and λ , thus explaining the small observed κ -production cross section. This work has been published: Phys. Rev. Letters, 11, 447 (1963). (Vigdor L. Teplitz and Pekka Tarjanne)

A calculation that should result in a quantitative understanding of the "electrodynamic" mass differences such as the n-p mass difference is being carried out. The calculational procedure is a blend of bootstrap and conventional quantum electrodynamic methods. (Mark Sharefkin and A. Charles Zemach)

We have found an expression based on the impulse approximation for estimating the inelastic contamination in elastic nucleon-nucleus polarization data in an effort to explain some of the discrepancy between the optical-model predictions and experiment. (Bandel Bezzerides)

The application of the Regge extrapolation procedure (mentioned in the preceding Physics Division Semiannual Report) to the case in which Regge poles are present but are ignored in the extrapolation has been completed. For a well-conditioned case with a large number of input points, it could be determined that a pole well into the right-half plane had been neglected, but this criterion is not sharp. In a more realistic case with only six input points the numerical errors inherent in the method rendered all results meaningless. (Graham H. Campbell, Joseph V. Lepore, and Robert J. Riddell, Jr.)

An attempt is being made in conjunction with Dr. David Sharp, Princeton University, to calculate scattering amplitudes from dispersion relations by a method that avoids both singular integral equations and cutoffs. The approximation is to take into account contributions from near double-spectral functions (and from S-wave single-spectral functions if subtractions are made), and to approximate the remaining contributions by crossed and uncrossed Regge poles. The position and residue of these poles are calculated

from unitarity with equations similar to but more complicated than those of Cheng and Sharp. The Regge formula is modified as suggested by Khuri so as to cut off the spectral function in the region where it is known to be absent. Unitarity equations can be obtained to fix the position of the cutoff, so that it does not appear as a free parameter. The cutoff can be made energy dependent; this is necessary if the scattering amplitude is to have a double-spectral function with the correct threshold properties. (Stanley Mandelstam)

PHYSICS OF THE NUCLEUS

Work has continued on the model in which fission fragments are represented by idealized charged-liquid drops constrained to spheroidal deformations. A computer program was written to integrate the classical equations of motion for two separating noncollinear spheroids of unequal volumes and eccentricities. The program was used to study the dynamics of fragment separation; for a large number of initial conditions, the translational and vibrational kinetic energies and angular momenta of the fragments at infinity were calculated. Simple approximate formulae relating these quantities to the initial conditions were obtained. By use of these relationships and initial conditions determined by assuming statistical equilibrium at the saddle point, expressions were derived for the probability distributions of final translational and vibrational kinetic energies and angular momenta. For the fission of elements lighter than radium, for which the model is applicable, satisfactory quantitative agreement with existing translational kinetic-energy data were obtained without the introduction of adjustable parameters. (James Rayford Nix)

A parametrization of nuclear shapes relevant to the discussion of fission (two spheroids supplemented by a neck in the form of a hyperboloid of one or two sheets) was found to give a simple and accurate approximation of nuclear saddle-point shapes throughout the periodic table. Applications are contemplated. (James Rayford Nix and W. J. Swiatecki)

By using a new technique of mica detectors, the cross section for the fission of gold by α particles was measured down to previously unattainable low levels. The interpretation of the data in terms of an improved formula representing the competition between neutron evaporation and fission has made it possible to obtain the first fairly reliable estimate of the height of a fission barrier for an element lighter than thorium. This makes it possible to deduce the ratio of the effective nuclear surface energy to the electrostatic energy with an accuracy of about $\pm 1\%$. [Donald Burnett, Raymond C. Gatti, Franz Plasil, Stanley G. Thompson (Chemistry), P. B. Price (General Electric), and W. J. Swiatecki]

W. J. Swiatecki's semiempirical mass formula, which includes shell effects and predicts nuclear masses and ground-state deformations, is being compared with experimental data to better determine the adjustable parameters. An attempt will be made to use this formula as a means of including shell effects in the determination of saddle-point configurations in the liquid-drop model of fission. (William D. Myers)

A paper entitled "Semi-Empirical Interpretation of Nuclear Masses and Deformations" was presented at the International Conference on Nuclear Masses (Vienna, July 1963), and will appear in the Proceedings. (W. J. Swiatecki)

THEORY OF MANY-BODY PROBLEMS

A many-body calculation of the low-temperature properties of liquid He^3 is being set up. The calculation will be performed on the Laboratory IBM 7094 computer, and the program is now being debugged. The primary results of the calculation will be the low-temperature equilibrium properties of this liquid, and these results should soon be available. It should also be possible to use the results to obtain some of the transport properties of this system, and to adapt the calculation to compute the equilibrium properties of nuclear matter. (Donald E. Beck and A. M. Sessler)

The nonideal Bose gas near the transition region is being investigated. Anomalous diagrams are summed by a self-consistent field approximation to the reaction matrix in the DeDominicis quasi-particle formulation. (Victor K. Wong and Andrew M. Sessler)

The Kohn-Hulthén variational method has been used to calculate the phase shifts in an elastic electron-hydrogen atom scattering for the $l = 1$ partial wave. Computations have been made on an IBM 7090 and 7094 for various energies below the lowest excitation energy of hydrogen, but because of poor convergence the results are not yet considered reliable, and the calculation is being revised. (Robert L. Armstead)

Work has continued on the Kaufman-Watson theory of the electrical polarization of a gas of neutral molecules.²² Most of the effort has been directed toward physical interpretation of the formulae for the electrostriction effects that were given in the preceding issue of this report. (Louis T. Klauder, Jr.)

The application of Goldstone-type linked-cluster perturbation expansion to the elastic scattering of electrons by atoms is being investigated. The perturbation diagrams are greatly simplified. When Hartree-Fock potentials are used to construct the starting basis, explicit formulas for the phase shifts are obtained. The method seems very promising and further investigation is in process. (Robert T. Pu)

A generalized optical-potential method for calculating atomic-scattering processes has been developed. The method has been applied to the elastic scattering of electrons by atomic hydrogen for the energy range 0 to 9.6 eV, and phase shifts for various partial waves have been obtained. These results are summarized in UCRL-10878.²³ (Robert T. Pu)

22. A. N. Kaufman and K. M. Watson, *Phys. Fluids* 4, 655, 931 (1961).

23. Robert Pu, A Generalized Optical-Potential Method and Its Application to the Scattering of Electrons by Atomic Hydrogen, UCRL-10878, June 1963.

A variational principle has been applied to the calculation of the equation of state. It can be used to obtain a perturbation expansion for the many-body problem, and to study the equation of state of a gas-liquid system, or the Ising model. It is shown that the Hartree-Fock approximation is not adequate for He^4 near the transition temperature. (Chi C. Sung)

A calculational program is under way on a one-dimensional model of atom-ion scattering. The system under study consists of two potential wells on a collision course acting on a particle initially bound by one of the wells. Results obtained for both direct scattering and rearrangement are in agreement at high energies with those from the Born and distortion approximations depending on the process considered. At low energies comparison will be made with different types of molecular-state descriptions. (James Quong and M. H. Mittleman)

The analysis of electron-sodium scattering being conducted with M. Mittleman is continuing. (Kenneth M. Watson)

PLASMA PHYSICS

A simple model of the sheath produced by a magnetized plasma in contact with a wall leads to shear in the $\mathbf{E} \times \mathbf{B}$ drift of the sheath particles.²⁴ Such a configuration is shown to be unstable, with growth rate proportional to the net charge. The result applies to a charged ($n_+ \neq n_-$) plasma in a magnetic field, with charges constrained not to flow along the field lines. (John Price)

The finite Larmor-radius corrections to the hydromagnetic-pressure tensor and energy equations have been calculated from the Vlasov equation for an arbitrary configuration. The resulting system of equations is not closed because of heat flow along the magnetic field. Investigation of the constraints on the initial distribution function imposed by the formal expansion (in m/e) has clarified the applicability of the results. (Alan Macmahon)

The propagation characteristics of ion cyclotron waves were determined from the Vlasov equation plus phenomenological collision terms for both ions and electrons. The spatial dispersion of the media leads to waves with spatially varying phase velocities in addition to the usual normal modes. The relative importance of the two wave types is being determined. (David L. Sachs)

The adiabatic invariant of the one-dimensional nonharmonic oscillator with time-dependent potential has been studied. Specifically, the first correction to the well-known lowest-order invariant has been obtained. This one-dimensional problem was studied as a prelude to calculating the first correction to the longitudinal adiabatic invariant of a charge particle in electromagnetic fields. The latter problem, which is similar to but more complicated

24. C. L. Longmire, Elementary Plasma Physics (Interscience Publishers, New York 1963).

than the one-dimensional problem, has been started. (Theodore G. Northrop, with Dr. Kruskal and Dr. Su of Plasma Physics Laboratory, Princeton University)

A program to calculate the corrections to the Debye-Huckel term for the free energy of a quantum plasma has been completed for the quasiclassical case. A new asymptotic method for treating large diffraction effects has been formulated and calculations are nearly complete. The work is now being written up as a thesis. (Sidney Putnam)

A book entitled "The Adiabatic Motion of Charged Particles" has been completed and published by John Wiley & Sons, Inc., New York, N. Y., 1963. (Theodore G. Northrop)

The stability of a magnetic mirror machine with conducting end plates has been investigated. The conducting end plates tend to stabilize the mirror system, since any deformation in the plasma must be accompanied by an increase in magnetic-field energy.²⁵ Eigenvalue theory for various energy principles was used to derive necessary and sufficient conditions for stability. Stability criteria for specific magnetic-field configurations and particle distributions were studied, and the maximum $\beta = 2p/B^2$ for which these examples are stable was computed. Certain geomagnetic oscillations were studied by means of a hydromagnetic model.²⁶ A variational principle was used to calculate the oscillation frequency of the model, and good agreement with the observed frequency was obtained. (Shalom Fisher)

WEAK INTERACTIONS

A study of the $K^{*0} \rightarrow \pi^+ + \pi^- + e^+ + \nu$ decay is now near completion. This process seems extremely interesting for the information it can yield on the low-energy $\pi\pi$ interaction. An experimental analysis of this process will allow a determination of the S-wave $\pi\pi$ scattering length (in the $I = 0$ channel), and provide independent verification of the A B C effect. (Nicola Cabibbo)

A further investigation of the theory of leptonic decays, based on the unitary symmetry,²⁷ has shown that this theory is in good agreement with a wide spectrum of experimental data. (Nicola Cabibbo)

ADVANCED ACCELERATOR STUDY

When the authorized a design study for a 200- to 300-BeV accelerator in April, theoretical work was started on a number of relevant matters.

25. R. E. Ellis, F. C. Ford, R. F. Post, and M. N. Rosenbluth, Phys. Rev. Letters 4, 166 (1960).

26. M. Sugiura, Phys. Rev. Letters 6, 255 (1961).

27. N. Cabibbo, Phys. Rev. Letters 10, 531 (1963).

There follows a list of some of the subjects, with a brief description of their current status.

Basic Parameters

Preliminary hand calculations for a variety of possible n values, injection energies, and accelerating frequencies were made for a 200 BeV alternating-gradient synchrotron to determine the required apertures, and number and length of magnets. At present we are developing an IBM 7094 computer program, which will permit more precise calculations of the basic configuration, as well as momentum compaction and the effects of various types of errors. (Alper Garren)

Long Straight Sections

As the size of the machine increases, it becomes still more important to incorporate long field-free sections for injection and extraction of particle beams. The long straight sections suggested a few years ago by Thomas Collins of CEA were studied first; subsequently it was realized that other configurations would permit arbitrarily long straight sections and this variation has been pursued in some detail. The most attractive arrangement to date involves two quadrupole doublets of 20 cm aperture separated by a field-free space about 120 meters long. This work will be continued with the computer program mentioned in the previous paragraph. (Alper Garren, Andrew M. Sessler, Lloyd Smith)

Magnetic Field Calculations

With the use of high-speed computers it appears feasible to circumvent much model magnet work by computing fields for a given steel and copper configuration, even including the effects of finite permeability and saturation. A computer program for this purpose is being developed in collaboration with Richard Christian of MURA. At present the program is capable of solving the infinite permeability case; the computations show adequate agreement with measurements of fields in existing magnets. The finite permeability feature is now in the debugging stage. (C. Fred Andrews, Andrew M. Sessler)

Slow Extraction

Many advantages are to be gained by conducting most experiments in areas far from the accelerator itself and by using primary proton beams that have been extracted from the machine. The feasibility of single-turn (or less) extraction has been demonstrated at CERN, but slow extraction, lasting 100 msec or more, is more difficult to achieve and is not yet operational at CERN. A computer program was written to study resonant perturbation of the beam, and preliminary results indicate that slow extraction is indeed feasible, though possibly requiring an improved control of field ripple during the flat-top period. (Thomas Mongan and Andrew M. Sessler)

Resistive Instabilities

It has been observed at MURA, Stanford, and the Brookhaven Cosmotron that an intense beam in a circular ring can develop violent vertical oscillations leading to severe losses of particles. A theoretical investigation of this phenomenon is in progress. The effect appears to result from the circumstance that the image charges and currents induced in the chamber wall by a coherent oscillation have an out-of-phase component due to the finite resistivity of the wall, which component causes the amplitude to grow for certain ranges of values of the relevant parameters. The longitudinal self-fields are subject to a similar phenomenon so that a circulating beam can be self-bunching even below transition energy. Quantitatively, these instabilities may impose a more severe limit on achievable intensity than the usual space charge limits; this subject is being pursued in more detail. (Lawrence J. Laslett, Verl K. Neil, and Andrew M. Sessler)

Orlov Nonlinear Accelerator

In recent months the Soviet physicist, Yu F. Orlov, has proposed a high-energy accelerator in which orbit stability is achieved by having the particles perform large-amplitude nonlinear oscillations in the horizontal plane. The idea seemed sufficiently promising that a working group of American accelerator physicists was assembled at Berkeley for a few days in June to analyze it. The conclusion was reached, in agreement with most Soviet experts, that it is not practical in its present form. A question arose concerning the long-time stability of the orbits, and a numerical computation was started here to investigate this point. This work is still in progress, but the indications are that if any absolutely stable orbits exist, they must be of very small initial vertical amplitude. (Andrew M. Sessler and Laurence Tribe)

Localized rf Stations

Preliminary layouts of the accelerator complex immediately showed that great savings could be made by locating all rf stations at one, or a few, points around the ring. An analysis was made of the effect of such a concentration on particle orbits, with the tentative conclusion being that a minimum of about four stations must be imposed. A computer program is being written to study this point more carefully. (Lloyd Smith)

Estimate of Neutrino Flux

An estimate of the neutrino flux available from a high-energy accelerator has been made. Pions and kaons are produced by proton bombardment of an external target and subsequently decay to produce neutrinos. The calculation is based on the Cocconi-Coester-Perkins formula for the momentum spectra of pions and kaons, and includes geometrical and Doppler-shift effects that control the neutrino flux at a detector. A simple formula is obtained for the neutrino flux (without focusing) that may be applied to an accelerator. The calculation also leads to simple upper bounds depending on neutrino energy

for the enhancement of neutrino flux to be expected if a focusing device is used to narrow the angular distribution of the pions and kaons. An estimate has been made, of the performance of a 200-BeV AGS accelerator and it is concluded that if neutrinos in the range of 1 to 2 BeV are of interest it is appropriate to operate the accelerator at a lower than maximum energy in order to take advantage of the higher repetition rate then possible. (Joseph V. Lepore and Robert J. Riddell, Jr.)

MISCELLANEOUS INVESTIGATIONS

The average rate of cosmic-ray-induced production of cosmic muon neutrinos (ν) has been calculated. The rate is

$$\Gamma_{\nu} = 1.25 \times 10^{-25} n_{\text{H}} / \text{cm}^3 \text{ sec},$$

where n_{H} is the concentration of interstellar or intergalactic hydrogen gas ($10^{-5} / \text{cm}^3 \lesssim n_{\text{H}} \lesssim 10^{-2} / \text{cm}^3$) and the cosmic-ray intensity is assumed to be uniform throughout the universe. The mean energy of the ν 's at emission is 170 MeV. Taking the lifetime of the universe to be the inverse Hubble constant, $H^{-1} \approx 10^{18}$ sec, and assuming the average ν production rate to have been constant during this time, one finds at present a ν concentration $n_{\nu} = 10^{-12}$ to $10^{-9} / \text{cm}^3$, corresponding to a mean energy density $\rho_{\nu} = \rho_{\bar{\nu}} \approx 10^{-34}$ to 10^{-37} g/cm³. This figure is several orders of magnitude smaller than the mean energy density of visible matter, $\rho_{\text{m}} \approx 10^{-27}$ to 10^{-31} g/cm³. (Alexander Maksymowicz)

The physical origins of the singularity in the exterior Schwarzschild metric were investigated. It was shown that this singularity is a consequence of the equivalence principle and the assumed validity of special relativity in a locally inertial frame. If these two principles are in fact true, then it is impossible physically to create a static situation for which the Schwarzschild radius a becomes equal to or greater than the radius of the star R . For a normal star ($\sim M_{\text{sun}}$), the physical conditions under which $a \simeq R$ are highly dynamic owing to rapid neutrino processes,²⁸ so that one cannot use the Schwarzschild metric to describe the situation. Possible direct physical manifestations of this singularity, discussed by Chiu,²⁹ seem therefore to be precluded by an apparent consistency between general relativity and the laws of elementary-particle interactions. (Alexander Maksymowicz)

The comprehensive study, described in previous reports, of the aberrations of quadrupole-magnet-beam systems has been concluded and a doctoral thesis describing it in detail has been written.²⁹ The thesis includes a detailed description and operating instructions for an IBM-7090 computer program that can simultaneously optimize several desired linear properties of general beam systems and will also yield complete information of third-order geometrical aberrations and on chromatic aberrations. This highly

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28. Hong-Yee Chiu, Supernovae, Neutrinos, and Neutron Stars, Report of Institute for Space Studies; Goddard Space Flight Center, NASA (1963).
 29. Philip F. Meads, Jr., The Theory of Aberrations of Quadrupole Focusing Arrays, (I) UCRL-10807 May 1963.

efficient code, written largely in machine language, can absorb the description of a beam system containing as many as 30 elements, adjust it to provide specified first-order properties, and calculate the aberration properties in a fraction of a minute. It contains provisions for generating a wide variety of oscilloscope plots that may be photographed to provide easily visualized summaries of the various properties of a system under study.

(Philip F. Meads, Jr.)

A report has been written that collects and treats in detail all the analytical and numerical work associated with the successful design of the recently constructed system for extracting a primary external proton beam from the Bevatron.³⁰ Linear and nonlinear analytical and numerical techniques and the various computer programs required are discussed, and the methods of incorporating various practical constraints into the parameter survey and optimization are described. (Philip F. Meads, Jr.)

Work on statistical-model predictions for high-energy interactions has been extended to include the energy spectrum of final-state particles and comparison with experiments in progress. (Graham H. Campbell)

30. Philip F. Meads, Jr., (II) Ion Optical Design of High Quality Extracted Synchrotron Beams with Application to the Bevatron, UCRL-10807
May 1963.

MATHEMATICS AND COMPUTING SERVICES GROUP (I)

Kent Curtis

(For November 1962 through April 1963)

Although the report for this period would normally have been included in the preceding Physics Division Semiannual Report, it was inadvertently left out; for this reason it has been included here.

During the period of this report members of the Mathematics and Computing Services Group have written the following programs for the Laboratory Research groups.

Physics

Accelerator Design

An electric focusing option was added to the deflector code, CYBOUT,¹ to permit a feasibility study of an electric focusing channel for the 88-inch cyclotron. CYBOUT, with this modification, is being used at the Rutherford Radiation Laboratory in the design for such an electric channel for their cyclotron.

The 88-inch cyclotron deflector system, as used in the 65-MeV a production runs, was studied by means of CYBOUT. An effort was made to determine if radial oscillation of the beam was responsible for the beam extraction at lower deflector voltages than had been predicted by early computer runs. The study was inconclusive. A transfer matrix to be used in external-beam studies was calculated for the above deflector system. (Herman Owens for Alper Garren)

Beam-development experiments at the 88-inch cyclotron required making numerous graphs of trim-coil phase effects and related graphs. These graphs were very useful in the successful development of four new particle beams. (Ardith Kenney, Herman Owen, and Byron Morgan for Alper Garren)

Calculations for the 88-inch-cyclotron beam-development experiments have been made. These include computations of the synchronous field, flutter, trim-coil settings, phase shift, predicted field, and other related information.² The following five cases were considered: 25-MeV helium, 25- and 50-MeV protons, 75- and 130-MeV a particles.

By using the linear-programming code, LP 90, trim-coil current settings were obtained for each trim coil individually. The combinations were made in order to operate the 17 trim coils on 11 power supplies. It is desirable to combine trim coils that tend to be running at approximately the

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1. Described in Physics Division Semiannual Report, UCRL-10349, May 1962, p. 45.
 2. Jonathan D. Young, Ardith S. Kenney, and Alper A. Garren, Computational Procedures in the Adjustment of a Cyclotron Magnetic Field by Trim Coils, UCRL-10075, March 1962.

same current level, regardless of polarity. However, one must also consider the ease with which the trim coils may be combined in the cyclotron itself. Also, if neighboring coils are combined, beam intensity may be more easily controlled during a run by manipulating the current and frequency at the console. Current settings were obtained for several sets of trim-coil combinations for 50-MeV protons in order to compare phase shift and gradient fluctuation.

Two series of calculations were done for 130-MeV α particles in different basic fields. The first used data from the fields obtained from the Grand Test run with the trim coils operating at the recommended current levels. The second used data from a field altered to simulate an "uncorrected" field, by taking the trim coil effects out of the Grand Test data.

The IBM 7090 code, INLIPR, which prepares the input tape for LP 90, has been modified to handle multiple right-hand-side elements and multiple cost rows. This permits the use of the parametric programming that sweeps out a whole sequence of optimal solutions. This method was used to determine trim-coil settings, frequency, phase shift, and gradient fluctuations for a variable momentum ranging from 0.25 to 0.271 times the base momentum $m_0 c$ in the case of 130-MeV α particles. (Ardith Kenney for Alper Garren)

CYDEA and INSCRL, IBM 7090 codes used to construct a linear program for determination of optimal trim-coil currents in the 88-inch cyclotron, have been revised to utilize a new linear-program code, LP 90, which is more efficient and versatile (with respect to parametric post rows). (Jonathan Young for Alper Garren)

A number of 7090 programs (CERTFY, DIFF, FIXIT, MAGTOR) were written and are currently being run on a production basis. The programs are used to analyze raw magnetic-field measurements taken on the Bevatron's auxiliary magnets. Analysis has been completed on 2 of the 17 Bevatron magnets to be tested. The steps followed in this analysis are:

1. The initial processing of the raw data is done by CERTFY. This program first transfers the data from paper tape to magnetic tape. At each point the magnetic-field measurements are taken twice and are then compared, averaged, and smoothed by CERTFY. The adjusted field is compared with and differences are tabulated between it and each of the calculated fields. At each point the calculated fields are derived in the first case from the surrounding 34 points, and in the second case only from points in the X direction. Further calculations include $B(X, Y)/B$ norm, where B norm is the field value at the magnet center.
2. DIFF computes and tabulates the difference between each point of two magnetic-field maps. The comparison may be $B_1(X, Y) - B_2(X, Y)$ or $BN_1(X, Y) - BN_2(X, Y)$, where $B_m(X, Y)$ is the adjusted $B(X, Y)$ map of CERTFY and BN_m is the $B(X, Y)/B$ norm map of CERTFY.
3. FIXIT was written to provide a means of correcting errors in a magnetic-field-value map as indicated by the output of CERTFY.
4. MAGTOR reads and stores from the output tape of CERTFY the magnetic field map $B(X, Y)$. After making corrections to specific points requested by the user, MAGTOR computes $B(X, Y)/B$ norm for each point. Further

MAGTOR computes (X, YI) for each value of X, where YI = the Y value along X corresponding to a $B(X, Y)/B$ norm of 0.10, 0.50 and 0.90, respectively. The (X, YI) values corresponding to 0.10, 0.50, and 0.90 are presented in tabular form and are plotted on the CRT. (Bert Albrecht for Magnet Test Group)

We developed formulas that represented in space an axially symmetric magnetic field in terms of its values on the axis of symmetry. The nature and location of the singularities of that field are being investigated by means of analytic continuation of functions of several complex variables. (Grove Nooney for Chuck Dols)

TABLE, a 7090 program, computes a table of drift-tube-gap voltage for the Bevatron Linac II and Maximum gradient per gap. (Barbara Steinberg for Rudin M. Johnson)

Graphs were hand-plotted using data from a study of extraction of particle beams from the high-energy alternate-gradient synchrotron. The graphs are radial phase plots of the beam under the influence of the extracting magnets. (Barbara Steinberg and Shirley Cassinelli for Andrew Sessler)

Several sessions were spent with the Davis Accelerator workers teaching them how to use our accelerator codes. (Herman Owens)

Moyer Group

NCQ, a FORTRAN program, written for the IBM 7090, calculates the average-charge density of a particular nucleus as a function of the skin thickness, the half-charge density radius, and the charge of the nucleus. It uses the Herman and Hofstader charge-density distribution function and the large and small components of the Dirac wave function as tabulated by Ford and Wills.³ The effective charge of the nucleus is also calculated. (Claudette Rugge for Jagdish Baijal)

Given the binding energy and the mass number for a particular nucleus, and specifying a range of neutron energies, a FORTRAN program, ESCAPE, was written for the IBM 7090 to compute the probability of a neutron escaping from the nucleus as a function of neutron energy. (Claudette Rugge for Don Hagge)

The numerical solution of a system of eight first-order differential equations was done to determine the focal lengths and principal planes of a nonuniform magnetic field for plane orbits. The program, FOCUS, can be operated in two different modes: (a) the nonsymmetric case, for which

3. K. Ford and J. Wills, Calculated Properties of the Mu-Mesonic Atoms, USAEC Los Alamos Report LAMS-2387, March, 1960.

initial conditions are given at a point outside the magnetic field, and (b) the symmetric case, for which the orbit is calculated in both directions from the center.

Runs made so far include two H magnets, with the magnetic field interpolated from a grid of measured data points; and a C magnet, with the magnetic field computed as the product of two functions, each of which depends upon only one space variable. (Loren Meissner for Robert Ely and John Poirier)

Assistance was given to various members of the Moyer Group on programs for analyzing 4-inch bubble chamber data. As the computational parts of the programs were written by the physicists, most of our assistance involved the input-output portions.

One by-product of this work was the development of a tape-to-tape program (DRUM-TO-CORE) for the 7090, input from which is in "standard" 650 card format and output from which is acceptable to FORTRAN. (Loren Meissner for the Moyer Group)

A measurement of neutron time-of-flight spectra from π^- -p collisions was made at the 184-inch synchrocyclotron. Data were displayed on a 400-channel RID1 pulse-height analyzer in which the channel number corresponded to the energy of the neutron. Runs were made with a hydrogen target full and empty. Accidental counts were also measured. TARGET is a 7090 program that calculates the true yield from hydrogen with its statistical error. Output includes CRT plots of yield per channel. (Barbara Steinberg for Don Lind and Barry Barish)

The 650 program ETHELBERT⁴ was used to compute orbits of secondary particles produced in the Bevatron. These orbit calculations determine the position of a target to be used as a beam source. A FORTRAN program named RAYTRACE⁵ was revised so that it would plot on the printer a graph of the intensity of the final image of the beam. (Victor Brady for John Poirier)

A pair of 7090 programs (BAMBIT and GAMBIV), designed to simulate a $\pi + \mu$ experiment, was completed. The programs compute lines of foci for a bending magnet, and energy spreads seen by counters along these lines. (Thomas Clements for Julius Solomon)

A FORTRAN program, DRYAD, was written to calculate the average solid angle subtended by a circular detector parallel to a circular source. (Barbara Levine for Selig Kaplan)

4. Physics Division Semiannual Report, UCRL-10349, May 1962, p.43.

5. Described in Physics Division Semiannual Report, UCRL-8936, August 1959, p. 23.

Crowe Group

Work continues on SELECT, a program for the 7090.⁶ This program selects or rejects particles (K-meson decay products) according to criteria concerning certain combinations of counters or counter planes (or both) in a broad-range spectrometer. If a particle meets these criteria, then a momentum value is assigned by a table look-up and an identification of the particle is attempted (e^+ , π^+ , or μ^+).

If the particle is identified, then an attempt is made to determine which of the six known decay reactions produced the particle. K^+ -decay spectra are formed from the particles thus identified. Several changes have been made to SELECT during the past 6 months. Input-output options have been added to make the program faster and more flexible. Various tables (such as momentum scales and solid angles) used in the data analysis may now be changed or appended without disturbing the program as a whole. Finally, the addition of new tables to SELECT made possible the analysis of more of the experimental data. Several spectra have been obtained from SELECT and least-square curve fits have been made to the spectra with VARMINT ZO EO ZO18).⁷ (James Eusebio for Robert Beck)

The final checking-out was done on SHOWER, a program in FORTRAN and FAP for the IBM 7090. This program constitutes a Monte Carlo Model for particle showers in heterogeneous material contained in a varying magnetic field. The program's output is a list of vectors, whose components identify the particles as to type, position and direction, and energy as they pass one of several check points. This information is gathered for each particle and all its decay products. Another program collates this output and produces histograms of the distributions with respect to energy of a given type of particle at a particular check point.

At present, the program is being used to study the showers produced by hitting a thin (0.08 cm) copper plate with electrons of various energies. All decay products are ignored and the output is an energy distribution of electrons emerging from the copper plate. (Marjory Simmons for Robert Beck)

A FORTRAN and FAP program, BBQ EXACT,⁸ was nearly completed on the IBM 7090. This program analyzes particle behavior in a spectrometer consisting of a quadrupole and a circular-pole-piece deflection magnet.

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6. Described in Physics Division Semiannual Report, UCRL-10572, November 1962, p. 67.
 7. Described in Physics Division Semiannual Report, UCRL-10349, May 1962, p. 46.
 8. Described in Physics Division Semiannual Report, UCRL-10572, November 1962, p. 66.

Checkout is complete for those parts of the program involved with tracking and recording passages through the various counter planes imbedded in the system. The field data, consisting of some 30 000 measured values, have been loaded on tape. Values not measured owing to obstructions have been interpolated by means of a fourth-order polynomial fit.

We anticipate using a table of potential values, rather than the field values, because the former require less storage space. A program performing the necessary integration is being checked out. (Les Wilson for Robert Beck)

Goldhaber-Trilling Group

Further work was done on the adaptation of the PANAL⁹ and PACKAGE¹⁰ programs (Alvarez, Bubble Chamber) for use in processing data from the Brookhaven 20-inch bubble chamber. PANAL and PACKAGE assemblies have been designated modification B; that is, PANAL-B and PACKAGE II-B. The above programs have been refined as follows:

1. PANAL Modifications and Additions

PANAL, as used by the Alvarez Bubble Chamber Group, assumes that data has been obtained from a three-view stereo system. Each track measured is checked for a minimum allowable proximity to the stereo axis of its measurement by subroutine CHOP. The best pair of views for stereo reconstruction is then obtained from subroutine CHOOSE. At present, the logic of these subroutines excludes the possibility of a fourth view; therefore, they are unavailable for 15- or 20-inch use. However, the routines are being modified for a four-view system. Meanwhile, tests for bad stereo alignment on a track, and the possibility of measurement in more than two views (in our case, an error), have been included in PANAL for 15- and 20-inch processing.

2. PACKAGE Modifications and Additions

PACKAGE also assumes a three-view stereo system. This assumption in PACKAGE is significant in the determination of measuring errors related to stereo orientation. These routines have been modified for a four-view system.

Other changes to PACKAGE are:

a. Provision for running more than one experiment with a given PACKAGE assembly. The present assembly contains the appropriate constants for six different experiments.

9. For a detailed description of PANAL, see Alvarez Physics Note No. 358, November 1961.

10. Described in Physics Division Semiannual Report, UCRL-10349, May 1962, p. 38.

b. A routine to calculate the momentum components of incident particles at the vertex point. By supplying these components to the fitting routines, the number of tracks that may be fitted at an interaction vertex may be extended to eight.

c. Corrections to the ZVERT routine for incident stopping tracks. This routine was outputting extraneous and confusing quantities for stopping particles.

d. Corrections to the method of averaging the azimuth angle obtained from the two stereo views. The original method was in error when tracks crossed the stereo axis in only one view.

e. Coding of new event types.
(Kirmach Natani for Sulamith Goldhaber, Gerson Goldhaber, and William Chinowsky)

Corrections and major additions were made to NKE3, a Monte Carlo program, for the calculation of the complete decay configuration of K^0 mesons decaying into π^\pm , e^\mp , and ν particles. The program is now able to tabulate certain angular, energy, and range-probability densities.
(Carl Quong for John Brown)

Additions and corrections were made to KMUTHY,¹¹ a Monte Carlo program, for the calculation of the complete decay configuration of K^+ mesons decaying into π , μ , and ν particles. Additional angular distributions are now calculated. (Carl Quong for John Kadyk)

As an aid to planning a forthcoming Bevatron experiment, a Monte Carlo program KO2, was written to generate K_2^0 events as they would appear in a 25-inch bubble chamber exposed to a K^- beam. The program calculates the flux of K_2^0 particles entering the fiducial region, total path length, and the parameters. In addition, the momentum distribution and the background from unwanted charged particles is also computed. (Bill Benson for John Kadyk)

Investigations were made of a program, F18-F, to calculate magnetic fields produced by an iron-pole magnet.¹² Although the program takes account of the iron saturation correctly, it was found impossible to make use of the routine due to slow convergence for the method used. (Bill Benson for John Kadyk)

The FORTRAN program, LDCAY, is being modified to treat the decay $\lambda \rightarrow r, p, \nu$.¹³ Further analyses in the laboratory system are being added. These are the Coplanarity, Transverse Momentum, and Impossible Configuration tests. (Gordon Sutherland for Carl Sandler)

11. Previously described in Physics Division Semiannual Report, UCRL-10572, November 1962, p. 61.

12. Richard S. Christian of Midwestern Universities Research Associates, Bubble Chamber Magnetic Field Program (F18-F), 1962.

13. John A. Kadyk, Generation of Three-Body Production and Decay Processes Following Phase-Space Distribution by Monte Carlo Method, UCRL-9614, April 1961.

PROT, a general set of routines for plotting graphs on the printed page, was written in FAP language and applied to the construction of histograms in the CHAOS program for data analysis of K^+ experiments. The faculty of making scatter plots of arbitrary pairs of quantities on the CRT was added to the program. Modifications were started to make the CHAOS data-analysis program more general, and independent of event types or EXAMIN programs. (Fred Andrews for Sulamith and Gerson Goldhaber)

Spark Chambers

Work has continued on the development of procedures for collection and reduction of spark chamber data. Emphasis was placed on completing a set of computer programs for the π - π experiment of the Lofgren Group. These programs have been written and are nearing check-out. A description of them follows:

Calibration. This is a set of programs that calculates the average film space coordinates of the grids in the spark chambers. No attempt is made to remove optical distortions. The grid intersections are taken in groups of four and a least-squares parabolic fit is made. The coefficients of these parabolas, as well as the average film space coordinates, are recorded on magnetic tape for later use by reconstruction programs.

Reconstruction. This set of programs will reconstruct the film data into a straight line defined in real space. The programs will calculate the intersections in two dimensions of the track and its image with the center grid line of the respective spark chamber. Optical distortions are corrected. The track and image intersection data are then used to construct the track in three-dimension space.

Numerical Integration. A number of methods for the numerical solution of a system of first-order differential equations was investigated, with particular regard to their application to orbit calculations. Orbit calculations generally do not require accuracy higher than 0.1%, but high speed is desirable. Because of the complicated interpolation procedure necessary to generate the magnetic-field components, the evaluation of the derivatives of each step is the most time-consuming part of the calculation. Therefore, an "open" method (which requires only one evaluation per step) was selected. Studies of methods of various orders with various step lengths demonstrated that a fourth-order method with a 2-in. step would provide the required accuracy with the smallest computer time possible. The program is used in the orbit integration program and, in addition, is available through the Computer Center Library.

Orbit Integration. A group of programs has been completed that will calculate the orbit of a particle through a magnetic field. The input consists of the coordinates of a point in space and the momentum components. The output consists of the coordinates of the end point of the orbit and the momentum components. A subsection of this set of programs is a routine that calculates the field components for a given point in space.

Orbit Reconstruction. This set of programs deals with the reconstruction of orbits of the secondary particles from the interaction in the hydrogen target. The film measurements of the sparks have been reduced to spatial coordinates and angles of points along the trajectories. In addition, both the vertical and horizontal transverse errors have been assigned to each measurement of position and angle. It is also assumed that matching of the downstream measurements has been accomplished. With this information, the program proceeds to match the upstream tracks. When the points for each secondary have been recognized and assigned, the initial momenta are estimated. Corrections due to stray field are made. Using the corrected data, an orbit is integrated and the final values derived.

Missing Mass and Vertex Constraints. The purpose of this program is to define the type of interaction that occurred with the hydrogen target. This is accomplished by use of three constraining equations, two of which refer to the vertex and one to the missing mass. Four sets of hypotheses are considered: (1) $\pi^+ - \pi^- - n$; (2) $\pi^- - p$; (3) $K^+ - K^- - n$; and (4) isobar. The χ^2 is calculated and the hypothesis accepted or rejected. If accepted, the invariant momentum transfer and dipion mass with their respective variances are derived.

In anticipation of a Moyer Group experiment that will utilize the TV-camera system, the following programs have been initiated:

Momentum Estimation. Preliminary studies indicate that we can make quite accurate momentum estimates, based on the formula $P \cdot \Delta\phi = k \bar{B} L$ or the equivalent form $P = k \bar{B} \rho$, where $\Delta\phi$ is the change in angle, \bar{B} is an effective average magnetic field, ρ is an effective radius of curvature, and L is an effective path length. Quantities such as \bar{B} , L , and ρ can be fitted to rather simple functions that depend only upon the positions and angles of entry and exit. Several functions tried with various magnetic fields have provided a high degree of accuracy.

Pattern Recognition. A previously written pattern-recognition program for recognizing line segments containing spark chamber tracks in a single view was extended. The principal features added to the previous work were: (a) provision of tolerances so that the sparks are not required to be exactly on a line, (b) concurrent accumulation of sums to be used later for least-squares fitting, and (c) conversion to FORTRAN language.

A three-dimensional pattern recognition program was completed. The tracks found in three views by the previous program were combined to form a common track in space. When a least-squares fit was made, the result was a point on a track and three direction cosines. The total time required in a test case to recognize these tracks (each consisting of 25 sparks in each of three views) and to form the three consistent tracks in space was 103 milliseconds. This time is composed of about 10 msec to recognize each of nine 25-point tracks plus about 13 msec to form the track in space. This program is available through the Computer Center Library.
(Armond Nirdlinger, Loren Meissner, and Donald Zurlinden)

A method to associate a "point of intersection" with three possibly nonintersecting curves of known smooth, but otherwise arbitrary, parametric representation was devised. Application was made to measured-particle trajectories to locate points of interaction.

By using the theory of dynamic programming, a method for reconstructing particle trajectories in a nearly field-free spark chamber was developed. (Grove Nooney for Donald Zurlinden)

A 7090 program was written to calculate particle trajectories through a magnetic field with a piece-wise constant approximation to the field and the resulting closed-form solution of the equations of motion. (Grove Nooney for Carl Noble, Jr.)

A FORTRAN program, INTGRT, was written to compute orbits of charged particles in a magnetic field. This program was to be used in the analysis of spark chamber experiments. (Victor Brady for the Lofgren Group)

Miscellaneous Physics Programs

A 7090 FORTRAN program, LEADER, was written to calculate numerically the fixed-angle dispersion relations for the photon-nucleon scattering amplitudes. The work was done to second order in the electromagnetic coupling constant, and the unitarity condition of the S matrix was used to calculate the required weight functions. The jump on the right-hand cut of the dispersion relations does not directly contain the Compton scattering amplitudes; however, a study of the energy dependence of the amplitudes at different angles provides some knowledge of those portions of the cuts that cannot be evaluated directly. On the right-hand cut, interactions are studied by allowing the exchange of a nucleon and a pion-nucleon pair, whereas on the left-hand cut, the strong interactions are estimated by including one- and two-pion exchange. In particular, evidence of the $\pi\pi$ interactions can be deduced.

This program involved solving several complex integrals of a symmetric nature, which introduced cancellations of a high order. This was further complicated by the appearance of a divisor of the order of 10^{-7} . In addition, difficulties arose in taking complex square roots since, in general,

$$(+\sqrt{a+bi})(+\sqrt{c+di}) \neq +\sqrt{(a+bi)(c+di)} .$$

After many unsuccessful attempts were made to eliminate these sources of error, the integrals were separated into real and complex parts that could be integrated directly. The cancellation problems were then overcome by using double-precision arithmetic. (Edna Williams for Elliot Leader)

A 7090 FORTRAN program, EIGENVALUE, was written to investigate the stability of n mutually coupled control systems, with particular bearing on Astron control at Livermore. This was a simple problem of

finding the eigenvalues of a symmetric matrix with unknown diagonal elements, and satisfying the condition that the determinant of the matrix must be zero. (Edna Williams for Edward Hartwig and Birchard Kortegaard)

A 7090 program, HYPERFINE 4, has been improved to double-precision accuracy.¹⁴ HYPERFINE 4 determines the best fit (by least-squares analysis) to any subset of the five parameters magnetic dipole, electric quadrupole, octupole moment, g_J , and g_I . The experimental data are in the form of frequency for an observed resonance vs the magnetic field of arbitrary hyperfine transitions for a given spin and angular momentum. Input and output data now contain up to 11 significant figures, but all internal arithmetic is done to 16 significant figures (that is, full double precision). (Edwin Towster for Atomic Beam Research Group)

A 650 program, WASSIX, was written to solve the Lyapunov equations for a reversible-reaction process in a boiler. (Edwin Towster for Darshenal Wasan)

The input-output subroutine IO-9 is being maintained. Necessary changes were made in the way the program is entered. (Joe Good for Joe Lach)

Adaptation of computer program PIPAMAL to ZO EO ZO18 was begun. PIPAMAL¹⁵ is a π -p phase-shift analysis program. (Joe Good for Bob Cence and Claude Shultz)

A FORTRAN program, SENSEN, was written to calculate the inversion matrix of a He³ fast-neutron spectrometer. To obtain the actual neutron spectrum, the experimental spectrum is corrected by removing recoil and wall effects. The program is concerned with the calculation of these effects. (Barbara Levine for Hsien-Tsan Wang)

A FORTRAN 7090 program, RIN, was completed; this fits data from a gamma-ray analysis on a scintillation spectrometer. The data represent the intensity of γ rays as a function of energy. The fit is found by least squares (by using a version of VARMINT) and the energies are found by interpolation of normalized Compton components. (Gordon Sutherland for John Ringle)

NMASS is a FORTRAN program written to use various theoretical formulas to compute the masses of nuclei. The program compares these results with tables of experimentally determined values. (Victor Brady for Wladyslaw Swiatecki)

14. Described in Physics Division Semiannual Report, UCRL-10572, November 1962, p. 70.

15. James H. Foote, Scattering of Positive Pions on Protons at 310 MeV Recoil Nucleon Polarization and Phase Shift Analysis, UCRL-9191, September 1960.

A 7090 FORTRAN program, GENEI, was written for the calculation of complete elliptic integrals of the first, second, or third kind. This program can be easily modified to calculate a general type of integral of the form

$$I = \int_0^{\theta} \frac{f(R)}{R} d\phi,$$

where $R^2 = m^2 \cos^2 \phi + n^2 \sin^2 \phi$, which include as special cases the standard forms of elliptic integrals. The method is based on Landen's transformation and utilizes the rapidly convergent scale of arithmetic-geometrical means. (Carl Quong for Graham Campbell)

A program to evaluate the integrals

$$H = \frac{2i}{r} \int_{\theta=0}^{\pi} \frac{(1-n \cos \theta) \partial \theta}{(1+n^2 - 2n \cos \theta)^{3/2}} \text{ and } \frac{dH}{dn}$$

was written. The calculated values were used to confirm some field measurements during the preparation of a spiral-ring model of a charged particle. (Dave Stevens for Ira Pratt)

A formula involving repeated Cauchy principal-value integrals was analyzed and put into a form suitable for computing. (Grove Nooney for Elliot Leader)

Chemistry

Several FORTRAN programs were written for the IBM 7090 in conjunction with experiments concerning the spontaneous fission of various elements.

Given a map of the number of fission counts with respect to the energy of two fission fragments, a program named FISRAG was written to calculate and tabulate, with respect to energy, (a) the average energy of the other fragment, (b) the total average energy, (c) the standard deviation in the energy distribution, (d) the total standard deviation, (e) the error about the mean, and (f) the total error.

STRUT was written to aid in looking at the angular distribution of the gamma quanta under spontaneous fission. This was done by calculating up to four Legendre coefficients as formulated by Strutinsky, given the spin, multipolarity, and a temperature factor. In addition to this, experimental γ -ray data were fitted to a Legendre polynomial, by means of an IBM 7090 FORTRAN least-squares subprogram.

ISOTOPE was written to record the number of α particles per channel per counter that occurred under spontaneous fission as a function of time. These data are resolved into α -particle distributions within isotope fractions. With the resolution of a calibration run, and the subtraction of the background,

the energy of each of the isotope fractions is calculated, along with the total number of counts within each fraction, and the FWHM of the isotope peaks. Given the half-life of a specific isotope, the total number of atoms can be calculated for that isotope as a function of time.

A Livermore IBM 7090 FORTRAN program was modified for use under UCRL, Berkeley's Monitor system. This program calculates the elements produced under spontaneous fission as formulated by David Dorn.¹⁶ (Claudette Rugge for Stanley Thompson)

By using the Los Alamos least-squares package for nonlinear parameters, a fitting function obtained from the ratio of the McIntyre modified Blair model to the Rutherford formula for the differential cross section was written in FORTRAN for the IBM 7090. In order to improve the fit on heavy-ion, elastic-scattering, and differential cross-section data obtained as a function of angle, this five-parameter program called ISOYA was modified several times in search of a best phase-shift function for the data. (Claudette Rugge for Homer Conzett)

Energy levels of various configurations of rare earth and actinide elements have been experimentally determined. The 7090 program BETABLE is a least-squares fit of theoretically predicted energy levels to the experimental data. The predicted energy levels are eigenvalues of various matrices with functional elements. The fitting program used, ZO EO ZO18 requires the partial derivatives of the predicted energy levels with respect to the variables of the matrix elements. These derivatives are evaluated numerically by differences. This program is currently in use, with a maximum of 20 variables and a matrix as large as 34x34; however, the method of evaluating derivatives is being examined. (Tom Clements for John Conway)

EIGENS, a 7090 FORTRAN program used to study atomic spectra, was revised. One of the subroutines of this program was revised to obtain more accurate eigenvalues and eigenvectors and to then order the eigenvalues. In addition, a revision was made to permit the use of a magnetic tape in determining the matrix elements. (Edna Williams for John Conway and Katheryn Rajnak)

CSRT was written to average sorted spectrographic data and to prepare data cards for input to another program. (James Eusebio for John Conway)

A 7090 program, KINK, was written to compute the value of an integral arising from dislocation theory in crystals. The integral is

$$E^1 = (R-1) \int_{Z_0}^{Z_0} \left[\left(\frac{R+1}{R-1} + \cos Z \right)^2 - \left(K_1(Z - Z_0) + \frac{R+1}{R-1} + \cos Z_0 \right)^2 \right]^{1/2} dz.$$

16. David Dorn, Mike Results - Implications for Spontaneous Fission, UCRL-6464, 1961.

Z_0 and Z_c are the two zeros of the integrand, and

$$0 < K_1 < 1$$

$$1 \leq R \leq 2.$$

The program is being modified to compute the value of two related integrals.
(Barbara Steinberg for Stanley Rajnak)

KEMSIX, a 7090 program, computes the concentrations of various chemical species present in solutions of sodium and sodium chloride in liquid ammonia. The calculation is a refinement of that of Berns.¹⁷
(Barbara Steinberg for Donald Levy)

A 650 program, T-7, was written for the calculation of the Debye Heat Capacity Function. (Carl Quong for Guenther Ahlers)

A least-squares program, HASTY, was prepared to calculate the composition of the various species of ruthenium (III) in an acid chloride solution from the total absorptivity of the solution and the known molar absorptivities of the species. Beer's law was assumed to be obeyed. The species contributing to the total absorptivity of the solution were considered to involve four species in Case I and six species in Case II. (Barbara Levine for Robert Hasty)

A 7090 FAP subroutine called LOUDLY, designed for use with FORTRAN programs, was completed to provide buffered read-in and processing of magnetic tapes prepared by certain usages of the ten-dimensional pulse-height analyzer.

Preliminary studies were begun to determine the revisions necessary to operate certain 7090 programs currently in use on the Control Data 3600 Computer. (Paul Concus for the Chemistry Group)

Biology and Medical Physics

A 650 program, LILYSTCYR, was written to aid in the health and safety monitoring of laboratory personnel. Employees routinely working with radioisotopes or involved in a "spill" are counted in the low-background whole-body counter with a 9-3/8 by 4 inch NaI(Tl) scintillation crystal. The Penco Analyzer provides a γ -ray spectrum consisting of the counts in each of 100 channels. The program computes counts per minute above background for predetermined energy regions and successively strips out the Compton effects of photopeaks from the lower-energy portions of the spectrum. Data useful for compiling a catalogue of normal human γ -ray spectrum parameters are also computed. (Edwin Towster for Medical Physics)

17. Donald S. Bern et al., Salt Effects in Metal-Ammonia Solutions: Sodium Chloride in Sodium-Ammonia Solutions at -33° C., J. Chem. Phys. 35, 1820 (1961).

Work continued on the 650 program, RATTEST, which was written in conjunction with an experiment to determine the effect of radiation on the body of rats and the transfer rate of radioactive isotopes throughout the rat's body. The 650 program employed means, standard deviations, ratios, t tests, correlation coefficients, and least-squares curve fitting to analyze the data. (Noel Brown for Pat Durbin)

Another 650 program, MICE, was written in conjunction with a radiation experiment involving mice. The experiment was concerned with determining the death rates of groups of mice exposed to varying levels of radiation and the effect of radiation on blood lipids. The program utilized correlation-coefficient analysis of variance, t tests, and least-squares curve fitting to analyze the data. (Noel Brown for Hardin Jones)

A series of subroutines was written for use with the Lab Programs Number 2.1 (Preparation of Isodose Contour Maps).¹⁸ The original subroutine assumed a rectangular dosage cross section for the cyclotron beam; the new subroutines provided for (a) triangular cross section, (b) constant cross section specified by an input table, and (c) up to 10 different cross-section tables, the table chosen being a function of the distance from the source. (Dave Stevens for John Lyman)

Certain chains of biological events are described by the system of differential equations $x' = Q(x)$, in which x is a vector of functions of time and Q is a vector the components of which are second-degree polynomials in the components of x . The polynomial coefficients are unknown. A scheme was devised for approximating the coefficients in Q so that the solution of the resulting differential equation would be a best fit for certain known values of x for given times. (Grove Nooney for Mark Horowitz)

Mathematics and Computing

A number of general utility programs have been written.

The program ZO EO ZO18,¹⁹ a function-minimization routine, is being revised. The new program ZO EO ZO32 allows for the following user-coded subroutines: HAPROX, for a better error matrix; UMALOW, to introduce constraints; and MAIN PROGRAM, to control input and output. Other changes are a more complete error control and a more flexible use of subroutine GTEST as a stepping procedure to help the main search. (Joe Good)

Several 1401 system programs were completed:

1. TAPE FILE, RECORD MERGER, AND EXTRACTOR: This program provides selective record and file duplication for one or more input tapes. The three primary purposes are:

18. Described in Physics Division Semiannual Report, UCRL-10572, November 1962, p. 74.

19. ZO EO ZO18 previously described in Physics Division Semiannual Report, UCRL-10572, November 1962, p. 76.

a. To copy one or more continuous groups of records or files from a long tape onto another tape to facilitate subsequent processing of that information (extraction).

b. To combine several tapes or continuous groups of records and files from several tapes onto one tape ("stacking" or "merging").

c. To produce a "corrected" or "updated" tape from a tape containing erroneous or extraneous information ("merging" or "deleting").

2. The standard tape duplicate was modified to permit "stacking" of several tapes onto one tape.

3. A program to generate BCD and binary tape records (as many as 1000 words in length) from BCD or octal card decks was written. The lengths of records are not necessarily integral multiples of six characters. This program is intended primarily to be auxiliary to the tape record and file merger, in order to correct and update tape files and records.

4. The tape record comparing program was rewritten to allow for starting the comparison with arbitrary files of the two tapes to be compared, and to allow rapid processing without error comments.

The 1401 systems tape dump is being rewritten to allow for page control, and to run on the LRL 4K 1401. (Gordon Sutherland)

Modifications and additions were made to the time-card accounting system,²⁰ including a new program to sort time cards by time-on, note-sequencing errors, and idle-time accounting.

A program UNBLK was written to produce an unblocked tape from a blocked tape. Essentially, this is a tape-copy routine that allows the user to rewrite a long record as several smaller ones. It may prove useful in handling blocked output from FORTRAN IV programs.

A symbolic disassembly program 9DSM was written. This produces a FAP-type symbolic listing or a FAP deck from a given relocatable column-binary object deck. Since our present object decks will not run under the system incorporating FORTRAN IV, this will make it possible to convert a program for which there is no source deck. (Dave Stevens)

A job-management analysis based on the Critical Path method is being programmed for an 8K 1401. This is an improved variation of the current PROLOG 1401 program now in use at LRL. This program is expected to involve logic that will lend itself to a variety of job and administrative management problems, which can be analyzed by Critical Path methods. Also involved with LRL Critical Path programming is the establishment of 7090 capabilities. Several current 7090 programs are being investigated. (Gordon Sutherland for Bill Bagot, Data Processing)

20. Described in Physics Division Semiannual Report, UCRL-10572, November 1962, p. 76.

A 7090 FORTRAN program, TRIDI, has been written for reducing an arbitrary real matrix A of order n to a similar tridiagonal Jacobi matrix J as a first step toward computing the eigenvalues and eigenvectors of A . The method used in this program is due to Lanczos, and involves the generation of two sets of biorthogonal vectors x_1, x_2, \dots, x_n and y_1, y_2, \dots, y_n such that

$$J = X^{-1}AX \text{ where } X = [x_1, x_2, \dots, x_n].$$

(Carl Quong)

Two FORTRAN integration subroutines are to be added to the IBM 7090 Library. SIMPN will integrate at the same time N integrals all having the same limits. MULSMP will calculate a N -tuple integral. Both use the Simpson's Rule recursion formulas. (Claudette Ruge)

Modifications were made to the SHARE Generalized SORT Program (IB9SORT, FORTRAN Monitor version) to make it compatible with the LRL FORTRAN Monitor system). (James Eusebio)

The behavior of sequences of numbers, as calculated by the random-number-generating 7090 program, RANF, was analyzed. Unsuitability of these numbers for consecutive use in simulation procedures, for which the event simulated is parametrized by three or more of these numbers and for which a known distribution of parameters is required, was discovered and remedies were developed for the discovered unsuitability. (Grove Nooney)

A study was made of the distribution of eigenvalues occurring in a highly nonlinear way in a singular second-order ordinary differential equation, the only boundary conditions for which are implied in the requirement that the solution belong to $L_2(0, \infty)$. (Grove Nooney for Glenn Schrank of Princeton University)

Assistance on general mathematical and statistical aid was given to various persons, mainly in the Mathematics and Computing Group. (Grove Nooney)

A revision to subroutine J4 EO CONV²¹ was written to eliminate certain undesirable features of the original version of this double-precision floating-point output routine.

A paper entitled "Standing Capillary-Gravity Waves of Finite Amplitude" was accepted for publication in the December 1962 issue of the Journal of Fluid Mechanics.²¹

Another paper written in conjunction with participants in the NSF 1962 Summer Program of Research Participation for High School Teachers was

21. Described in Physics Division Semiannual Report, UCRL-10572, November 1963, p. 77.

entitled

"Tables for the Evaluation of $\int_0^{\infty} x^{\beta} e^{-x} f(x) dx$ by Gauss-Laguerre Quadrature"

and was accepted for publication in the July 1963 issue of Mathematics of Computation.²¹

Work was completed on further aspects of capillary-gravity phenomena. The problem of the capillary stability of an inviscid incompressible fluid contained in an inverted rectangular channel was investigated. Work of previous authors on this problem had followed either the static approach, which is in general an incomplete one for determining over-all stability, or the dynamic approach, which is mathematically intractable in all but the simplest of cases. It was shown that for the considered problem the two approaches would necessarily yield the same stability criterion so that only the simpler static approach need be used. Based on this work, a paper entitled "Capillary Stability in an Inverted Rectangular Channel" was presented in January 1963 to the American Astronautical Society at the Second Symposium on Physical and Biological Phenomena under Zero-g Conditions. The paper will appear in the publication of the Symposium by Plenum Press in their Advances in Astronautics series later this year.

An investigation was completed of a condition described in recent papers on finite-amplitude standing waves to ensure the uniqueness of the obtained perturbation solutions. The investigation showed the uniqueness condition to be unacceptable because it excluded all physically realizable fluid depths, thus making it impossible to satisfy in practice. An acceptable revision of the uniqueness condition was derived, which, when used, would still retain the validity of the previously obtained solutions. A paper based on this work was entitled "On the Uniqueness of Certain Standing Waves of Finite Amplitude" and was submitted to the Journal of Fluid Mechanics.

Assistance was given to other members of the Laboratory in solving mathematical and computational problems. (Paul Concus)

A report was prepared and is now in the process of being published: J. D. Young, Linear Computations of Function Approximations with Application to Fitting and Editing Two-Dimensional Data, UCRL-10734, March 1963.

Several FORTRAN 63 programs are being written for the Control Data 3600. These programs, of mutual interest to the Computing Groups at Livermore and Berkeley, are being written as a cooperative effort. Several of the programs are in the process of being checked.

A generalized internal sort program, SORT63, was written in FORTRAN 63 for the CDC 3600. The routine will sort an array of consecutive items, each item consisting of consecutive words, on keys specified by the user. The array must be wholly contained in memory and is replaced by the sorted array on return to the calling program; no additional temporary storage is needed.

The sort may be done in ascending or descending order and in addition may be specified as an algebraic sort (words considered as sign quantities)

or a logical sort (the sign bit in a word treated like any other bit). This is a general-purpose program that may be used as a subroutine for subsidiary sorting tasks or as a rapid-sort program whenever the entire array to be sorted may be placed in memory at once. (Bill Benson and Barbara Steinberg)

Two versions of a general root finder were written in FORTRAN 63 for the CDC 3600, one (RZERO) using real, the other (ZZERO) complex arithmetic to find the zeros of any analytic function. The number of roots desired, initial guesses for the roots, and various tolerances that determine convergence of the iteration progress may be supplied by the user. The program has a wide variety of uses, such as finding eigenvalues of differential operators and arbitrary matrices, and finding roots of transcendental equations. (Bill Benson)

FORTRAN IV and FORTRAN 63 versions of the Simpson's Rule integration subroutine DI EO SMP2 were written. (Dave Stevens)

Other programs to be written are a generalized Bessel-function routine (Dave Stevens), a table-lookup and linear-interpolation routine (Barbara Levine), and an arccos, arcsine and arctan subroutine (Carl Quong).

Computer Operations and Systems Programming

Operations

During the past six months, utilization of the 7090 Computer by Berkeley Research Groups has continued at the rate of 4 shifts per week.

The 709 computer, on a grant from IBM, has increased utilization from 1 to 3 shifts per week. This increase is due to development and production work on the SMP and QUEST Systems. This utilization is expected to increase during the next interval to 4 shifts per week and continue at that rate until early in Calendar Year 1964, when it is planned to replace the 709 by a 7044.

In December 1962 an additional 1401 was installed at the Laboratory. This 1401 is used primarily as an input-output processor for the 7090.

The Laboratory still uses a significant amount of time on the 7090 installed at the Campus Computer Center. The conversion of the Laboratory's 7090 to a 7094 was deferred until June 1963. In June, in addition to conversion to a 7094, the Laboratory 7090 will also have a 1301 disc file and an additional 32 000 words of storage added to the system.

A digital plotter and a 1407 inquiry console are expected to be attached to one of the 1401 computers in June 1963.

During the next interval, the Laboratory expects to install another large-scale computer comparable to an IBM 7094 or CDC 3600. (Marvin Atchley and Paul Rhodes)

A study of the sources and frequency of magnetic-tape errors is being undertaken. Goals of the study are the determination of optimum policies for testing and replacement of magnetic tapes. Two 1401 tape-testing programs and a 7090 data-analysis program were written.

Early results of the study revealed that the Laboratory procedure of stripping used magnetic tapes was not an effective one; as a result, this procedure has been abandoned. Further changes in Laboratory tape procedures are expected to result from the study. (Walt Hutchinson)

Systems Programming

Principal systems-programming efforts during this interval were in the following areas:

1. Maintenance and modification of existing 7090 programming systems.
2. Preparation of the IBSYS FORTRAN-IV System for use at the Laboratory.
3. Completion of debugging and documentation of a 1301 disc programming package.
4. Preparation of a set of standard programs to be used in evaluating computer hardware.
5. Extending and refining 1401 Systems Programs.

A new EXEM program was written and made available to users of the FORTRAN Monitor System. This program gives the user closer control over input-output errors by passing on to him information about the nature of such errors and allowing him to take action on the basis of this information. (Myron Myers)

Additional subroutines were prepared and incorporated in the Monitor System to make more efficient use of the on-line clock. Alternative versions of these subroutines making use of the clock on the Campus 7090 were also written. (Robert Belshe)

The IBSYS FORTRAN-IV System was received and is being modified for use at the Laboratory. Appropriate time-accounting routines are being incorporated in it; its tape assignment routines are being changed to conform with Laboratory operating procedures; and various subroutines (including CRT plotting routines) are being modified so that they will run under the new system. In addition, manuals for programmers and operators are being prepared, and consultation services are being offered to users who wish to change over to the new system. (Douglas Brainard, Myron Myers, Robert Belshe, and William Benson)

The 1301 disc programming package has been debugged (at the Western Data Processing Center, UCLA) and documentation on it has been distributed to users. (Myron Myers)

A set of FORTRAN programs to be used in the evaluation of computer hardware was written and tested on the IBM 7090 and 7094, the Philco 212, and the CDC 1604. (Douglas Brainard)

A compilation of information regarding the IBM 1401 Computers at LRL, Berkeley, and the programs available for use on them has been distributed to computer users. A card-listing program was written for the 1401 to replace a previous less-sophisticated program of the same nature. A specialized "Paper Tape-to-Magnetic Tape" program has been written for the 1401 (with 1011 Paper Tape Reader). This program does some editing of the data read before transmitting it to magnetic tape. (Walt Hutchinson)

MATHEMATICS AND COMPUTING SERVICES GROUP (II)

James A. Baker

During the period of this report, members of the Mathematics and Computing Services Group have written the following programs for the Laboratory research groups.

PhysicsAccelerator Design1. AGS Field Design

A numerical method was formulated for solving a boundary-value problem of a nonlinear elliptic partial-differential equation in an irregular two-dimensional region. The problem arises in the determination of the magnetic field that would be present during the operation of the proposed alternating-gradient synchrotron (AGS). Study of the convergence of the iterative procedures involved in the method of solution is continuing. (Paul Concus for Lloyd Smith)

Assistance was given in the development of a program by Richard Christian* for the design of magnets for the proposed AGS. This program will be able to compute, by means of given tables of permeability, the median-plane fields to be expected from a given magnet shape and current value. (Fred Andrews)

Work was begun on the design of an interpretive system for specifying and combining constituent units of an AGS, with particular attention to their focusing properties. (James Eusebio and Robert Belshe for Alper Garren)

2. AGS Drift-Tube Cell Design

The program called NIRNS (Rutherford Laboratory, Harwell, England), which determined properties of linear accelerator drift tube cells for specified geometries, was modified for more efficient use in π mode and at higher energies. The program was used in studying properties of drift-tube cells operating in π and in 2π modes at 100 and 200 MeV.

LINYIP, designed to project kinematic properties of a drift-tube cell of known energy through successive cells to some specified higher energy, was written for the IBM 7090. The program provides the values of parameters for a linear accelerator tank for acceleration over the given range. YALEDT (Yale University) is then used to trace particles through a tank having those parameter values. A complete write-up of this program is available in the form of a programmer's note. (Jonathan Young for Alper Garren)

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3. AGS Coupling Effects

Studies were made of the equations of motion in an AGS consisting of two differing regions that occur alternately. Of particular interest was the question of coupling between the radial and the vertical motion. Because of the iterative nature of the transcendental equations, and the large amount of computation time required when using the true equations, various algebraic expansions were used to approximate the functions. (Barbara Levine and Laurence Tribe for Andrew Sessler)

4. 88-Inch Cyclotron

CYDER, TRICOR, BCOR, and INDELB were written for theoretical studies of the 88-inch cyclotron. CYDER computes derivatives and the radial gradient for the main-coil and the trim-coil effects. TRICOR, used with CYDER, computes the effective gradient in the main coil and trim coils for specified currents. BCOR makes a correction in the main field by changing the current in the main coil. INDELB computes a synchronous field $B_s(R)$, an interpolated iron field $B_{int}(R)$, the difference ΔB between them and the gradient index $K(R)$. The relative change in path length induced by the flutter is obtained from previous DORO calculations.¹ The particle and the desired energy at the reference radius must be specified for the calculation. From a field tape containing radial profiles of measured iron fields at various currents, a new iron field may be obtained by interpolation. Either the desired current in the main field may be specified or the new field may be set equal to the computed synchronous field at a desired radius. Computations have been made for α particles and protons at energies from 10 to 30 MeV and for α particles from 90 to 130 MeV. (Ardith Kenney for Frank Selph)

The parametric programming feature of the LP 90 codes was used to obtain frequency, phase shift, gradient fluctuations, and optimal settings of the 88-inch-cyclotron trim coils for α particles over the range of 20 to 80 MeV, with the momentum varying from 0.1 to 0.2 times the base momentum m_0c .

FOURCO was written to compute Fourier coefficients a_n and b_n for harmonic analysis of measured field data for the 88-inch cyclotron. Various constants and spiral angles are also calculated. A new field may be constructed by using the coefficients to compute fields $B(R, \theta)$ at any specified θ interval. This method will smooth the measured field data and compute better intermediate-field values than those obtained by interpolation in the isochronization code DORO. FOURCO may be run as an independent program, as a chain link with DORO, or as a subroutine for DORO. (Ardith Kenney for Alper Garren)

5. Iron-Free β -Ray Spectrometer

A feasibility study was begun on a new iron-free β -ray spectrometer. The first phase consisted of making second-order calculations of a magnetic-field shape by using azimuthally varying fields to indicate whether further

1. Described in Physics Division Semiannual Report, UCRL-9017, December 1959, p. 30.

studies were advisable. SPECTB, written by Jonathan Young, was used for these calculations. The results from these calculations, while encouraging, were inconclusive and indicated that higher-order terms were needed. Consequently, a second phase was begun. BRAYS, designed to solve the exact equations of motion with magnetic fields represented up to sixth order and with features that automate certain iterative procedures, was written and preliminary calculations were made. (Herman Owens for Andrew Sessler)

6. Magnet Test

The programs CERTFY, DIFF, and FIXIT,² which analyze data taken by the "Rapid Mapper,"³ were improved and applied to the analysis of three Bevatron "C" magnets, the 20-foot Bevatron velocity spectrometer, 40-inch Sagane magnet, 25-inch bubble chamber magnet, and the 88-inch switching magnet.

The following new programs were written for the 7090:

- a. INSERT corrects errors in magnetic-field measurements taken by the "Rapid Mapper" which the initial processing program, CERTFY, is unable to correct. It also provides more detailed information about the raw magnetic-field measurements;
- b. PROFILE computes the average radial profile from 88-inch-cyclotron magnetic-field measurements;
- c. EXTEND interpolates a 3-deg magnetic-field-value map from the field values of a 120deg map at the same current level and 3-deg maps taken at higher and lower current levels. (EXTEND was used to obtain 3-deg maps of all 88-inch-cyclotron iron-field magnetic measurements);
- d. COMPCO computes for each R, θ the coefficients of the least-squares polynomial of a given degree that approximates the measured field at various current levels;
- e. FURNISH computes a magnetic-field map from the coefficients of COMPCO at any desired current.
(Bert Albrecht for Magnet Test Group)

The Campus double-core 704/7090 compatibility code 00BC704 was converted for use on our 7094, and two 704 programs were run.
(Jerry Borges for Alper Garren and Philip Meads)

Runs were made using a program 4P, which analyzes and designs beam systems in a hypothetical particle accelerator. (James Eusebio for Alper Garren)

2. Described in the previous section of this report.
3. Peter Watson, Brief Description of Operations and Performance specifications of LRL Rapid Magnet Field Mapping Systems, Engineering Note MT 164, August 8, 1963.

Moyer Group

Assistance was given to various members of the Moyer Group in the construction of programs for analyzing 4-inch bubble chamber data. A group of programs has been written for processing tapes from cards that have come from the IBM 650. These programs, which run on the 7094, select particular sets of data, test for certain tolerances, and rearrange the numbers into the proper form for analysis by programs written by the physicists. (Loren Meissner and Marilyn Mahan for Robert Kenney)

Work was started on a program to determine the target position necessary to produce a desired secondary-particle beam from the Bevatron, and to compute the focusing effects of the Bevatron magnetic field on the beam. This program is an expansion of the IBM 650 program named ETHELBERT.⁴ (Victor Brady and Loren Meissner for John Poirier)

Crowe Group

MUDECAY was written to compute a muon-decay spectrum. A basic theoretical spectrum that includes a factor representing internal radiative corrections is calculated. Next a convolution integral, which involves this function along with distributions representing experimental bremsstrahlung and ionization losses, is computed. Finally, the convolution integral of the spectrometer-resolution function with the theoretical spectrum is calculated. The object of this computation is to find those values of the Michel parameters, p and z (which appear in the original theoretical spectrum), for which the final spectrum gives the best fit with experimental data. (Marjory Simmons for Philip Beilin)

EZNLBS was written to generate a table of a function for each of several sets of parameters. (Anthony Schaeffer for Robert Shafer)

Results from BBQ EXACT⁵ were checked against wire orbit data and changes were made in the logic to improve speed and to allow for particles hitting the pole faces both in the quadrupole and spectrometer. (Leslie Wilson for Robert Beck)

Trilling-Goldhaber Group

Some minor modifications were made in the data-analysis program CHAOS to increase its generality and flexibility. (Fred Andrews for Sulamith and Gerson Goldhaber)

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4. Physics Division Semiannual Report, UCRL-10349, May 1962, p. 43.
 5. Described in Physics Division Semiannual Report, UCRL-10572, November 1962, p. 66.

PANAL⁶ was modified to provide for four views, for running with either two or three tape channels, for new types of measuring equipment, and for reading all input from tape rather than cards. Some new event types were added to PACKAGE.⁷ (Kirmach Natani for Sulamith Goldhaber, Gerson Goldhaber, and William Chinowsky)

GRAPHX, which fits a least-squares polynomial to specific distributions of events from the bubble chamber, was prepared; this program displays the input points and the fitted polynomial either on the CRT or on the CAL-COMP Plotter. (Noel Brown for Sulamith Goldhaber and Thomas O'Halloran)

Spark Chambers

Moyer Group

Work has continued on the development of procedures for collection and reduction of spark-chamber data. A set of programs has been initiated for processing the data for a π^- -p experiment. A description of these programs follows.

A program was written for the 1401, which merges tapes of raw spark-chamber data and converts them to a format acceptable to the 7094. (David Stevens)

WINSUM processes these merged tapes, producing for certain selected run numbers an event list for scanning (which contains the event number, pulse-height-analyzer channel number, detector number, and time conversion), as well as accumulated statistics that provide information for a pulse-height-analyzer histogram for each event type and detector.

FIELD is a FORTRAN subroutine which does a two-dimensional Lagrangian interpolation to obtain the Z component of the magnetic field at an arbitrary point of a region in the X-Y plane. One complication was introduced because it was necessary to measure the field on a nonrectangular grid.

SPAM is a revision of ORBIT3 for the particular geometry of this experiment.⁸ This routine estimates the momentum of a particle from its observed positions and angles of entry to and departure from a region of known magnetic field. The program estimates an initial momentum, computes an orbit, and obtains a corrected momentum. The time of flight, which is also measured for each spark chamber event, is combined with the corrected momentum and path length to determine the mass of each particle. (Leslie Wilson)

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6. For a detailed description of Alvarez Group IBM 7090 Program PANAL, see UCID-1650, Nov. 1961.
 7. Described in Physics Division Semiannual Report, UCRL-10349, May 1962, p.38.
 8. Described in the preceding section of this report.

MIDDLE - This program finds the most likely point of coincidence in space of a number of measured tracks that do not quite intersect. (Leslie Wilson)

The spark-chamber pattern-recognition program TRAX, written for the 7094, was rewritten to operate on the DDP-24. (David Leppaluoto)

Lofgren Group

Work was begun on a 1401 program to read a BCD magnetic tape produced by one or more SCAMP measuring machines, to test for and correct certain types of errors, to produce separate output tapes for each of the different SCAMP machines, and to print out an event list giving the event number, scanner, and machine number. (Armond Nirdlinger)

The programs used in Carl Noble's π - π experiment were completed. Solid-angle and aperture-correction calculations for the Sagane magnet were made. (Donald Zurlinden)

Miscellaneous Physics Programs

CONTOUR was written for the numerical evaluation of the Dispersion Theory approach to proton-Compton scattering. This approach involves the evaluation of multiple principal-value integrals over a semi-infinite range. The results of the above theory are to be compared with experimental data. (Edna Williams for Elliot Leader)

PLASMA was written to compute values of the plasma-dispersion function in the first quadrant. The plasma-dispersion function is described by Fried and Conte.⁹ (Noel Brown for David Sachs)

FUSION was written in connection with a mirror machine experiment. Under various field configurations, the program computes the ratio of the plasma pressure to the magnetic-field pressure, and determines the maximum value of this ratio for which the mirror machine remains stable. (Noel Brown for Shalom Fisher)

A simple numerical method was devised for a certain model of electron scattering by atoms. (Fred Andrews for Robert Pu)

IMBESL was written to find roots of equations involving Bessel functions. (Barbara Steinberg for Andrew Sessler)

The HYPERFINE 4¹⁰ and HYPERFINE F-9 programs were revised to provide double-precision accuracy (16 significant figures) in all internal arithmetic. HYPERFINE 4 determines the best fit (by least-squares analysis) to any subset of the five parameters: magnetic dipole, electric quadrupole,

9. Burton D. Fried and Samuel D. Conte, The Plasma Dispersion Function, (Academic Press, New York City, 1961).

10. Described in Physics Division Semiannual Report, UCRL-10572 November 1962, p. 70.

octupole moment, g_J , and g_I . The experimental data are in the form of frequency for an observed resonance vs the magnetic field of arbitrary hyperfine transitions for a given spin and angular momentum. Input and output data now contain as many as 11 significant figures. HYPERFINE F-9 computes a table of sequential values of magnetic field vs resonance for arbitrary hyperfine transitions. If the derivative of the frequency with respect to the field passes through zero, another table is made for the values of the field in the neighborhood of the zero derivative. Input and output data now contain as many as 15 significant figures. (Ed Towster for Howard Shugart)

GEOMAG was designed to plot contour lines of constant declination and of constant inclination of the earth's magnetic field, on a plot of longitude and co-latitude. The contour lines are determined by finding the roots of $D(x, y) = D_i$ and $I(x, y) = I_i$, where D_i and I_i are the values represented by the contour lines, and $D(x, y)$ and $I(x, y)$ are computed from given formulas. Formulas containing 48 coefficients were used. The resulting plots are to be compared with those obtained from a new set of formulas having 450 coefficients. (Barbara Garnier and Leslie Wilson for Harry Heckman)

TABS was written to summarize reports on the use of scanning machines, to show the amount of time spent by each scanner and the amount of time required for maintenance, subdivided according to various categories. (Barbara Garnier and Krehe Ritter for Wes Weber)

PINT was written for the calculation of the population-level distribution of a beam of neutral hydrogen for given values of ionization, excitation, and de-excitation cross sections. The calculation requires the numerical solution of a system of differential equations for each level. (Carl Quong for Klaus Berkner, Sherwood)

Work was done involving the PDP-5, a small computer to be used in a cyclotron experiment, primarily as a data-gathering device involving only a small amount of editing. To assist the engineering group, which is designing the interface between the cyclotron and the PDP-5, a set of service routines (for typewriter input-output, paper tape input-output, and memory dumps) were written. In addition, work was begun on the programs necessary for the data-gathering and physical calculations, and on special-purpose subroutines.

A 7094 program, JAB, was written to facilitate the use of the PDP-5. This program performs the assembly of a PDP-5 program written in pseudo-machine language. It lists the program and punches column binary cards for direct input to the PDP-5. (Donald Zurlinden, Myron Myers, and Loren Meissner for Roy Haddock)

Chemistry

Measurements were made of the fission cross section for helium-ion-induced fission of various heavy elements as a function of excitation energy of the compound nucleus formed on absorption of the helium ions. Two function-fitting subroutines that use the Los Alamos non-linear-parameter least-squares package were written to describe the ratio of the partial widths of the fission to that of neutron emission as a function of excitation energy. One subroutine defined this function in terms of three parameters: effective fission barrier, neutron-level density, and fission-level density, as reported by J. R. Huizenga.¹¹ This theory could be applied only to data above the fission barrier. The second subroutine included an additional parameter, the fission-barrier width, as derived by W. J. Swiatecki. This four-parameter function permitted a fit of data both above and below the fission barrier. The results of this program, BARRIER, are contained in a UCRL report now being prepared.¹²

In connection with the study of the γ -ray spectrum occurring under spontaneous fission, SIGAR was written to sort γ -ray energy data obtained from a four-dimensional pulse-height analyzer. The data were sorted according to the mass ratio of the fission fragments. Approximately one million events were processed by this program in order to search for γ -ray structure and to look at the Doppler shift. (Claudette Rugge for Stanley Thompson)

The Los Alamos non-linear-parameter least-squares package is used in a fitting subroutine called LEVY, which was written to calculate and fit

$$Y(x) = A_1 \sin 2\pi (A_2 x + A_3) + A_4.$$

(Claudette Rugge for Richard Levy)

BETABLE¹³ was revised to accept a maximum of 20 variables and an input matrix as large as 50 by 50. The matrix-diagonalization routine BC HOW is used. Subroutines to search for minima by stepping along coordinate directions, as well as by stepping to the vertices of a cube around an initial point, have been added as supplements to VARMINT (ZO EC ZO13), the main minimizing routine. A subroutine to optimize the increments used in evaluating numerical derivatives has been incorporated. Work has begun on a subroutine to avoid the computation of derivatives of points far from a minimum and to preserve the VARMINT error matrix for use in succeeding runs. (Thomas Clements for John Conway)

TRITENS was written to evaluate the matrix elements of certain triple tensors for use in computing electron-energy levels in atoms. (James Eusebio for Kathryn Rajnak)

11. J. R. Huizenga, Helium-Ion Fission of Bi, Pb, Tl, An, Phys. Rev. 126, 1 (1962).

12. F. Plasil, W. J. Swiatecki, and S. Thompson, Fission Barrier of Th²⁰¹, UCRL-11079 (to be issued).

13. BETABLE was described in the preceding section of this report.

FISNU was written to calculate the average number of neutrons emitted from each fission fragment of a given nucleus (as a function of the mass number of the fragment and the total kinetic energy), and to calculate the first moments of an empirical-frequency function. (Carl Quong for Stanley Thompson)

Two programs, LAMBDA and AHLERS, were written to evaluate certain given functions from measured parameters and to integrate these functions. (Carl Quong and Penelope Collom for Guenter Ahlers)

PRIME2 was written in connection with a low-temperature nuclear-alignment experiment. The program calculates parameters describing the degree of alignment as a function of temperature, and displays the results in graphical form on the CAL-COMP Plotter. (Noel Brown for Richard Frankel)

Some runs were made with an adaptation of a standard least-squares fitting program. (Carl Quong for Yun Shen, Inorganic Chemistry)

CSRT,¹⁴ designed to average sorted spectrographic data, was modified so that it can process more than one input tape. (James Eusebio for John Conway)

A set of programs called DIABLO was written for reducing paper-tape data to magnetic tapes, which are input to the CAL-COMP Plotter and the VARMINT Program. (Anthony Schaeffer for Arthur Springer and John Meriweather, Nuclear Chemistry)

Several revisions to the subroutine SOFTLY,¹⁵ which provides buffered read-in and processing of magnetic tapes prepared by the ten-dimensional pulse-height analyzer, were written. The revisions provide faster processing of the tapes prepared by the present analyzer, and allow processing of the tapes prepared by the new analyzer due to arrive soon. A more comprehensive program called TALLY, which incorporates these revisions and is compatible with FORTRANIV, was written to allow the tape-processing operations to be performed more rapidly. (Paul Concus for Bernard Wilber)

The least-squares curve-fitting program POLYGNU was revised to read its input and write its output on magnetic tape instead of punched cards. The input tape will be produced by the Chemistry Group directly on a tape recorder. (James Eusebio and Jerry Borges for John Conway)

MAGNET was written to determine the magnetic rigidity, field strength, gradients, radius of curvature, magnetic elements, phase-space ellipses,

14. CSRT was described in the preceding section of this report.

15. Described in Physics Division Semiannual Report UCRL-10572, November 1962, p. 71.

and first-order optical parameters of bending magnets and arrays of quadrupole magnets. The program also determines the performance of a combination of those bending and focusing elements needed to produce the various beam specifications requested. (Edna Williams for Claude Ellsworth)

Assistance was given to several members of the Laboratory, primarily from the Chemistry Group, in solving specific computational and mathematical problems. (Paul Concus and Grove Nooney)

Biology and Medical Physics

Space radiation encountered by an astronaut was analyzed by ASTRO. The radiation consists largely of an isotropic flux of high-energy protons. The program evaluates several single integrals, and produces curves that show the radiation dose (in spheres of tissue) due to the ionizing effect of the primary protons from this flux, as a function of tissue depth. A major revision called ASTROS incorporates into the calculations the effects of secondary protons. This problem requires the evaluation of a triple integral. For efficiency, the program makes a table of the inner two integrals and interpolates in this to the outer integral. (Barbara Levine and Anthony Schaeffer for Palmer Steward)

A recently written program called IODINE makes use of a least-squares fit for experimental data; iodine concentrations (in micrograms) are determined for protein-bound iodine in serum. The output is displayed in graphical form on the CRT. (Noel Brown for Gilles LaRoche)

RATTEST¹⁶ was modified to include CAL-COMP plotter output. RATTEST is a least-squares fitting program prepared to fit experimental rat data to a sum of decreasing exponentials. (Noel Brown for Patricia Durbin-Heavey)

Work was completed on a paper, written jointly with Mark Horovitz, on the numerical inversion of convolution operators.¹⁷ (Grove Nooney for Aldo Rescigno)

ANGSCT was written to integrate tabulated data originated in a study of angular scattering light. (Anthony Schaeffer for Elizabeth Gross)

16. Described in Physics Division Semiannual Report, UCRL-10572, November 1962, p. 74.

17. Mark Horovitz and Grove Nooney, UNFOLD--A Computer Program for Analyzing Linear Systems for Calculation in the Time Domain, UCRL-10927, July 1963.

Health Chemistry

Three programs replacing existing 650 programs were written for this group. One called AQUASSY was written to analyze samples for α and β - γ deposition and concentration. A second, WEATHER, was written to tabulate mean wind speed and direction of a 3-month period. A third, FIQUIN, was written to sort and update file cards for air samplers. (David Stevens for John Peck)

The Spectrometer Analysis Program RIN was updated. (Gordon Sutherland for John Ringle)

Metallurgy

XYZ was written to fit data points to a curve by least-squares methods. (Jerry Borges for Marcus Borom)

Some runs were made with an adaptation of a standard least-squares fitting program. (Carl Quong for Didericu Hasselman)

DISLOC was written to calculate slopes and integrals. (Barbara Steinberg for Stanley Rajnak)

Electronics Engineering

Some studies were made concerning the numerical inversion of a convolution integral. (Anthony Schaeffer for Philip Dunn)

The programs LARGE and LARGER, which perform summations of series of Bessel functions, were written. (Leslie Wilson for David Large)

Health Physics

An investigation was made of properties of sampling procedures used in examining film emulsions. The procedures were modified to be statistically meaningful in connection with experiments in the reconstruction of neutron energy spectra. (Grove Nooney for Richard Lehman)

Bio-Organic Chemistry

A decision method was developed for determining whether several chains of biological events represented by series of measurements might be regarded as observations of a single biological process. (Grove Nooney for Vivian Moses)

Budget

A new 7094 FORTRAN code, SKED 92, was written for Budget applications, to replace the IBM 650 code in use for about 4 years.¹⁸ The new code can handle data for a larger number of research programs and subprograms, as required by recent Laboratory growth. It also provides more detail and summary information on costs of operation for the Berkeley and Livermore sites for 3 fiscal years. Plans were begun for additional subroutines that will organize the output to meet specific needs of the Budget Group. (Ardith Kenney for George Pappas)

Livermore

ARTN was written for the CDC-1604 to calculate the principal value of arc tangent (x) for any single precision value of x. The method is due to Kogbetliantz.¹⁹ This program provides 10 significant digits of accuracy. (Carl Quong for the Livermore Library)

Mathematics and Computing

Theoretical Studies

Characterization was made, in part, of the distribution of eigenvalues of several nonlinear singular ordinary differential equations. (Grove Nooney for Glenn Schrank, Princeton University)

A study was begun of the near-resonant harmonic solutions of Duffing's differential equation $\omega^2 D^2 y(\theta) + y(\theta) + R[y(\theta)]^3 = A \cos \theta$ for small values of ω and positive R. (Loren Meissner)

More revision was done on a previous paper entitled "On the Uniqueness of Certain Standing Waves of Finite Amplitude."²⁰ The revision eliminates, rather than attempts to salvage, a perturbation method that is not entirely successful in solving inviscid standing-wave problems. Work was also done on extending previous results on the capillary stability of inverted fluids in two dimensions to include fluid-vapor interfaces expressed in parametric form. (Paul Concus)

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18. SKED 92 was previously described in Physics Division Semiannual Report UCRL-9017, December 1959, p. 30.
 19. E. G. Kogbetliantz, Computation of ARCTAN N for $-\infty < N < +\infty$ Using an Electronic Computer, IBM Journal of Research and Development, January 1958, pp. 43-48.
 20. This paper was described in detail in the preceding section of this report.

TRACINT, which interpolates as many as six functions of two variables for a specified value of one of the functions, was written. Complete descriptions of the problem, process, and program are available in the form of a programmer's note. (Jonathan Young for Alper Garren)

General-Purpose Programs

Assistance was given in the statistical analysis of methods for generating uniform distributions of numbers in many dimensions. (Grove Nooney)

A method of successive approximations was devised for the global solution of certain problems of ordinary differential equations involving multi-point side conditions. (Grove Nooney)

An invited address, "Mathematical Models, Reality, and Results," was prepared and delivered before the Fifth Medical Symposium, Endicott, New York. (Grove Nooney)

A program called FUNCAN for performing linear approximation computations was written.²¹ This program can be used for harmonic analysis, level fitting, and editing of data. (Jonathan Young)

EIGEN was written to calculate the eigenvalues of real symmetric matrix. The method is due to Magnus R. Hestenes.²² (Carl Quong)

A general-purpose minimization program (VARMINT) for a function of several variables was revised to improve speed and convergence.²³ (Joe Good and Anthony Schaeffer)

Routines called TLU363 and TLU were written to perform table lookup with linear interpolation on a three-dimensional table $\mu = f(x, y, z)$, and a one-dimensional table $y = f(x)$. (Barbara Levine)

Preliminary work was started to utilize C11BCTR, a program to calculate the coefficients of rational- and continued-fractions approximations to analytic functions. (Carl Quong).

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21. Jonathan D. Young, Linear Computation of Function Approximation with Application to Fitting and Editing Two-Dimensional Data, UCRL-10734, March 1963.
 22. Simultaneous Linear Equations and Determination of Eigenvalues, National Bureau of Standards Applied Mathematics Series 29, pp. 91-93.
 23. Described in Physics Division Semiannual Progress Report, UCRL-10349, May 1962, p. 46.

A newly written program FREUD prints a descriptive analysis of an IBSYS input deck. (David Stevens)

A FORTRAN IV Sampler was prepared. (David Stevens)

A project has been started that will evaluate and test library programs. (Carl Quong and Marilyn Mahan)

Those SHARE Library subroutines which have been used most frequently were converted to versions compatible with FORTRAN IV and IBSYS.

Systems Programs

Systems programming effort during the period of this report was in the following areas:

FORTRAN II Monitor System (7094)--Maintenance and Modifications

1. The Berkeley Campus CAL-COMP Plotter programming package was modified to run with the Laboratory FORTRAN II system, enabling computer users to produce output on tape for subsequent plotting on the CAL-COMP Plotter. (William Benson)

2. Various changes to FORTRAN II were made to permit the transferring of control between both 7094 systems, IBSYS and FORTRAN II, thus allowing a mixed set of jobs to be run through the combined system. (Robert Belshe and Myron Myers)

IBSYS Monitor System (7094)--Maintenance and Modifications

1. Many modifications were made to IBSYS to permit running the system on the Laboratory 7094. (Robert Belshe and Myron Myers)

a. Time-accounting routines were added that are compatible with the machine-time accounting system in effect for the 7094.

b. Operator-IBSYS communications were modified to permit better control of a monitor run through a single set of operating procedures for both systems, IBSYS and FORTRAN II.

c. IBSYS and FORTRAN II were combined so that control can be switched between systems automatically, permitting the running of a mixed set of jobs.

d. IBSYS was put on the 1301 disk file to allow random access to the various system components, as well as to free a tape unit.

2. Several utility programs were written:

a. The FORTRAN II CRT routines were modified for use during IBSYS runs. (William Benson)

b. The Library routines FXEM (execution-error handling routine) and FPTRP (floating-point trap handling routine) were modified to allow greater flexibility in error detection and recovery. (William Benson)

c. A general-purpose input-output routine was written. This routine communicates directly with the trap supervisor IOEX, and thus provides greater flexibility and requires less overhead time than alternative routines that use IOCS.

d. A generalized 1301 disk file input-output routine was completed and a connecting set of FORTRAN-compatible routines was developed. (Myron Myers)

e. An IBSYS version of the CAL-COMP Plotter routines was completed. (William Benson)

3. The input-output system (IOCS) and its relation to Laboratory computing was investigated. The particular problem of reading mixed-mode tapes was solved by replacing the look-ahead bit-scanning scheme by a simple trial-and-error method. (William Benson)

4. A version of the combined IBSYS-FORTRAN II system, which will operate on the Campus 7090, was completed. (Robert Belshe)

5. An IBSYS user's manual containing control-card information, programming information, deck-setup information, subroutine documentation, and some general statistics concerning operating characteristics was written. (Douglas Brainard, Myron Myers, David Stevens, Robert Belshe, William Benson)

6. The system editor that actually constructs the IBSYS system on tape or disk file was modified and corrected. (Ted Ross, Gail Wampler, and Charles Stevenson, IBM)

IBSYS Monitor System (7040)--Preparation, Maintenance, Modification

1. The development of system programs to handle time-accounting functions, to print operator messages from an executing program, and to allow a program to interrogate the 7040 clock and interval timer was begun. (David Stevens)

2. An extensive list of differences between 7094 IBSYS and 7040 IBSYS was compiled. (David Stevens)

3. Another program written was SAMPLER, which illustrates various kinds of input to the compiler and assembler, together with the corresponding output. (David Stevens)

Diprogramming System Development (7094)

A diprogramming system (STEREO) has been designed. Use of this system is expected to increase the effective capacity of the Laboratory's 7094 computer by a factor of approximately 1.7. The plan is to load a program into each of the two memory banks of the computer, and then to switch back and forth between the two programs in such a way as to overlap input-output operation with computing insofar as is possible. The system uses many parts of the IBSYS system and will be compatible with almost all IBSYS programs. The expected system release date is January 1, 1964. Progress was made in the following specific areas:

1. Agreement was reached on a set of specifications that define the problem and outline the proposed method of attack (Douglas Brainard, James Baker, Robert Belshe, William Benson, Myron Myers, Ted Ross, Charles Stevenson, and Donnelly Watson)

2. A computer clock was designed to provide both system control over the running of all programs and an accurate means of accomplishing time accounting. (Robert Belshe)

3. Plans were made to modify the IBSYS input-output system. The trap supervisor, IOEX, must operate when traps occur from both memory banks of the computer. An investigation of some recursion problems encountered in input-output trapping has led to some modifications of the input-output system as a whole. (Douglas Brainard, Myron Myers, William Benson).

A switching-criteria study, involving a Markov-process mode has been initiated. (Grove Nooney)

4. The system editor that creates the system on tape or disk file was modified to create system components that load into either memory bank. (Ted Ross, Gail Wampler, Charles Stevenson)

5. Various system components (compiler, assembler, loader) were reoriginized in memory in an attempt to foresee major difficulties that might arise. (Ted Ross, Gail Wampler, Charles Stevenson)

6. The specialized input-output routines written for IBSYS were kept compatible for Diprogramming usage. (Donnelly Watson)

Miscellaneous System Programming

1. A special IBSYS-FORTRAN II time-card processor was written to aid in accounting for computer usage. (Robert Belshe and David Stevens)

2. Various computer-error diagnostic routines were written to aid the IBM customer engineers in detecting obscure machine errors.

3. A 7094 Simulator for use on the 7040 was developed. (David Stevens)

4. The design of an expanded, more flexible set of CRT routines for use with IBSYS was initiated. (William Benson)

5. A series of computer-usage studies was made on the 7094 with a piece of equipment called the hardware monitor; this machine was used to determine the efficiency of programs and programming systems by directly measuring the amount of overlap of computing with input-output operation. (Robert Belshe)

6. A series of runs was made on the Honeywell 800 in order to evaluate the advantage of multiprogramming. A substantial advantage appears to be present, but quantitative results were difficult to interpret. (Douglas Brainard)

7. A sorting routine was written for the CDC 3600. (Barbara Steinberg)

8. A study of ways to increase the usefulness of the IBM 650 version of FORTRAN was begun. The first step is an attempt to simplify the incorporation of subroutines into programs by having subroutines available in symbolic form. (Victor Brady)

9. Preliminary studies were made of the software package for the DDP-24, with particular attention to FORTRAN. The design and operation of the DDP-24 were investigated together with its real-time capabilities. (Donald Zurlinden and David Leppaluoto)

10. In August 1963, a 1407 typewriter and a CAL-COMP plotter were attached to the LRL 1401-I. A program (PARASITE PLOT) was written to output the contents of specially coded tapes (produced by the 7094) to the plotter. The PARASITE PLOT program is executed simultaneously with a tape-to-printer program, and uses whatever "free time" is available within the print cycles. When both the plotter and the printer are running, the printer operates at about 95% of its maximum speed and the plotter at about 60% of its maximum. (Walter Hutchinson)

Computer Operations

During the past 6 months, the 709 computer, on a grant from IBM, has increased utilization from three shifts per week to four shifts per week. This increase is due to production and development work on the SMP, QUEST, and Spiral Reader Systems. Utilization is expected to continue at this rate until early in calendar year 1964, when it is planned to replace the 709 by a 7040 computer.

The Laboratory still uses from one shift to two shifts per week on the 7090 computer installed at the Campus Computer Center.

The conversion of the Laboratory's 7090 to a 7094 was accomplished in June 1963. A 1301 disk file and an additional 32 000 words of storage were also added to the 7094 system in June 1963. The utilization of the 7094 reached four shifts late in July.

A digital plotter and a 1407 inquiry console were added to the 1401-I in August 1963.

A systematic program of sampling and retesting magnetic tape was initiated during this reporting period. (Paul Rhodes, Marvin Atchley, Walter Hutchinson)

The Laboratory now has one 729-V and two 7330 magnetic-tape drives in use at remote locations to prepare data for the 7094.

In October 1963, alterations were made in the Building 50-A computer wing to house a DDP-24 computer (Computer Control Company) and an IBM 7040. These machines are to be delivered early in the next reporting period.

In December 1963, two of the Laboratory's 1401 computers will be replaced by double-printer machines. (Paul Rhodes and Marvin Atchley)

PHYSICS RESEARCH

Edward J. Lofgren in Charge

K^- -PROTON INTERACTION

E. F. Beall,* V. Cook,** W. R. Holley, D. Keefe, L. T. Kerth,
J. J. Thresher,*** C. L. Wang, and W. A. Wenzel

The analysis of the data collected on K^- -p interactions between 700 and 1400 MeV/c has almost been completed. About 15 000 K^- -p elastic scatterings have been selected as an unbiased sample of "good-fit" events; of these a few hundred are events in which the recoil proton suffers an elastic scattering in the carbon spark chamber plates and are useful for polarization information. Some rescanning continues and the best normalization procedure is being determined.

Results based on a preliminary normalization were presented at the meeting in Siena, Italy, in October of this year.

SCANNING AND MEASURING EQUIPMENT

D. Keefe, L. T. Kerth, and W. A. Wenzel

The SCAMP scanning and measuring projector has been the only precision measuring device available for handling spark chamber photographs in this period. Two further SCAMPs with a similar basic conception but more sophisticated design are nearing completion. They will have separate buffer storage for the digitized measurement information and will share a common magnetic-tape unit.

Preliminary work on a programmed-spot automatic-film-scanning system (SASS) has been begun. As this system requires an on-line computer, a DDP-24 has been purchased primarily for this purpose. A study of the peripheral equipment necessary is in progress.

π - π INTERACTION

D. Keefe, L. T. Kerth, C. M. Noble, J. J. Thresher,
W. A. Wenzel, and T. F. Zipf

The scanning, measurement, and analysis of data collected in a spark chamber experiment on dipion production was continued. About 80% of the

* Presently at the University of Maryland, Department of Physics, College Park.

** Presently at the University of Washington, Department of Physics, Seattle.

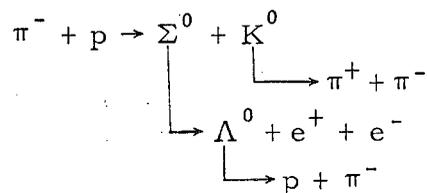
*** Work performed while on leave from the Rutherford High Energy Laboratory, Chilton, England.

events photographed at an incident π^- momentum of 4 BeV/c have been scanned and 7 000 events have been measured. The IBM 7090 program for track reconstruction, correction of optical distortion, orbit integration through the magnetic spectrometer (Sagane magnet), and kinematical fitting has been completed and debugged. Certain selection criteria still remain to be decided upon, and the pictures taken at primary momenta of 2 GeV/c and 3 GeV/c (π^+ and π^-) have still to be scanned and measured.

Σ - Λ RELATIVE PARITY

A. R. Clyde, B. Cook,** B. Cork, R. L. Crolius, D. Keefe,
L. T. Kerth, W. M. Layson, and W. A. Wenzel

A spark chamber experiment, operating with a parasitic beam of π^- at 1.2 GeV/c momentum, has been completed. We hoped to accumulate enough events of the type



-in which the end products amount to six charged particles-to permit a direct determination of the Σ - Λ parity from the correlation of the production plane, Λ decay plane, and the Dalitz-pair plane. This method is free from assumptions about the hyperon form factor. Events of the required type were photographed typically only once per 10^9 incident pions and in the available running time not enough were accumulated to provide a conclusive answer on the relative parity. The number of direct $\Sigma^0 \rightarrow \Lambda^0 + \gamma$ decays followed by the conversion of the γ rays, will, however, allow a determination of the polarization of the Σ^0 in the production reaction.

ELASTIC AND INELASTIC p-p SCATTERING AT 2 to 6 BeV

A. R. Clyde, B. Cork, D. Keefe, L. T. Kerth,
W. M. Layson, and W. A. Wenzel

The object of the experiment is to measure with high accuracy the elastic-scattering cross section and isobar-production cross sections, with special emphasis on both very high and very low momentum-transfer events. The equipment has been constructed and installed in the external proton beam at the Bevatron, and preliminary electronic debugging has begun. Three separate types of target are being used-polyethylene, liquid hydrogen, and gaseous hydrogen-to allow the whole range of momentum transfers to be studied conveniently. Recoil protons are selected with respect to momentum by a deflection in a bending magnet and are focused by a quadrupole lens onto the detecting scintillation-counter telescopes.

ELECTRON LINEAR ACCELERATOR

Douglas W. Pounds

During the period May through October, beam time for experimenters amounted to 321 hours or about 30% of the available time. The low use rate for this period results from a series of component failures requiring a total of 15 weeks down time. The remainder of the time was utilized in machine improvements and making experimenter setups.

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

The installed electron paramagnetic resonance spectrometer and associated equipment have become operational and are producing good data.

The operating maximum of the accelerator has been raised to 8 MeV, with an increase in intensity to 170 mA/pulse.

The outlook for the coming 6-month period is for less down time with a resulting higher use rate, an increase in the EPR program, and further work toward increasing the length of the accelerator cavity.

PUBLICATIONS

1. Edward J. Lofgren and Walter D. Hartsough, Bevatron Improvements, UCRL-10866, presented at the 1963 International Conference on High Energy Accelerators held in Dubna, USSR, August 1963. Paper will appear in the Proceedings.
2. Glen R. Lambertson, High-Intensity Phenomena at the Bevatron, UCRL-10867, presented at the 1963 International Conference on High Energy Accelerators held in Dubna, USSR, August 1963. Paper to appear in the Proceedings.
3. W. A. Wenzel, Bevatron External Proton Beam, UCRL-10868, Presented at the 1963 International Conference on High Energy Accelerators held in Dubna, USSR, August 1963. Paper will appear in the Proceedings.
4. E. F. Beall, W. Holley, D. Keefe, L. T. Kerth, J. J. Thresher, C. L. Wang, and W. A. Wenzel, Elastic K^- -p Scattering Between 700 and 1400 MeV/c presented at the Conference on High Energy Nuclear Physics held in Siena, Italy, October 1963. Paper to appear in the Proceedings.

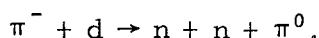
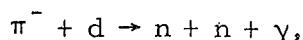
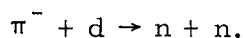
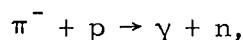
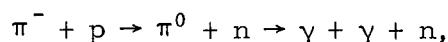
PHYSICS RESEARCH

Burton J. Moyer and A. Carl Helmholz in charge

INTERACTIONS OF LOW-ENERGY NEGATIVE PIONS IN
HYDROGEN AND DEUTERIUM

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

The progress of this experimental program, which has been reported in the previous Semiannual Report,¹ has reached the point of final analysis of data on the measurement of the following array of reactions:



The analysis of the data on the last three reactions has been completed, with the determination of the following values for the cross sections at 80 deg in the c. m. system and at 51 MeV incident-pion energy:

$$\sigma(\pi^- + d \rightarrow n + n + \gamma) = (3.167 \pm 0.660) \times 10^{-29} \text{ cm}^2/\text{steradian},$$

$$\sigma(\pi^- + d \rightarrow n + n) = (3.068 \pm 0.375) \times 10^{-28} \text{ cm}^2/\text{steradian},$$

$$\sigma(\pi^- + d \rightarrow \pi^0 + n + n) = (6.56 \pm 0.48) \times 10^{-28} \text{ cm}^2/\text{steradian}.$$

The radiative absorption cross section and the S-wave pion relations indicate the value of $T = 0.76 \pm 0.16$, in agreement with theoretical calculations, in which T is the ratio of reaction rates for Reaction (4) to Reaction (2). The calculation of $S = 1.51 \pm 0.40$ from the cross-section measurements, and the value $S = 1.92 \pm 0.33$ measured by direct detection of both reactions, are in agreement with value $S = 1.74 \pm 0.26$ calculated from the S-wave pion relations, in which S is the ratio of reaction rates for Reaction (3) to Reaction (4). An indirect measurement comparing radiative captures in hydrogen and deuterium gave a value of $S = 3.37 \pm 0.46$, which is in agreement with other indirect measurements. This discrepancy appears to be due to difficulty in monitoring the number of pions captured in hydrogen and deuterium.

This experiment is described in more detail in UCRL-10977 (Low-Energy Negative Pion Interactions in Deuterium).

1. Physics Division Semiannual Report, UCRL-10862, May 1963, pp. 48-49.

The following subsections that do not include author's names describe the work of the entire Moyer-Helmholz group.

EXPERIMENT ON THE CHARGE-EXCHANGE INTERACTIONS IN ELASTIC π p SCATTERING

For the past three years this group has been engaged in a study of the nature of the resonance-like behavior occurring at certain energies in the pion-nucleon interactions. These phenomena were first identified by careful measurements of the total cross section in π^\pm -p collisions. They have subsequently been studied in considerable detail by our measurements of the differential scattering cross sections for both positive and negative pions on protons over a distribution of energies in the region of the resonances. This information has provided strong evidence concerning the angular momentum states that could be involved in the resonance-like behavior, but it has not clearly indicated whether the cross-section enhancements are due to resonances in the conventional meaning of the word, (e. g., the real part of the phase shift for a particular state of angular momentum passes through 90 deg), or whether the enhancements are due to some rapid change in absorption processes producing the observed behavior in the total cross section. Ambiguities of the Minami type remain also.

With the intent of reducing such ambiguities and providing clearer evidence on the nature of the phenomena, we performed measurements of the polarization of the recoil proton in π -p scattering at a number of energies. This information has provided important further conditions to be met by any theory purporting to explain the phenomena, but the precision of the polarization measurements was not sufficiently great to remove all ambiguities.

In the attempt to find a phase-shift characterization of the π -p scattering, it has been impossible to obtain a unique set of such parameters. This is not surprising in view of the large number of phase shifts required, since we must include real and imaginary parts for both states of isotopic spin and for states of angular momentum at least through $l = 3$. The progress in the over-all project of characterizing the π -p scattering has been all that could be expected within the time available and in view of the techniques that could be applied within this time, but it is still necessary to provide the further constraints that can be imposed by (a) a knowledge of the differential cross section for elastic charge-exchange scattering, and (b) a more precise determination of the polarization of the recoil proton. The experiment reported for this period is the first of these two areas of investigation.

A study of charge exchange requires the detection of a neutral final state consisting of π^0 and n. The neutral final-state condition is identified by the absence of a signal in a scintillation counter that surrounds the hydrogen target when the input counters on the π^- beam line indicate the entrance of a pion into the liquid hydrogen target. Identification of this neutral final state as one involving only a single π^0 is accomplished by observing the showers produced by the π^0 decay photons in an array of spark chambers completely surrounding the hydrogen target and its anticoincidence jacket.

Each of the spark chambers occupies the position of the face of a cube, in an overlapping manner, which provides a complete surrounding of the target with sensitive spark-chamber volume. Each chamber possessed 35 steel plates 1/8-in. thick so as to provide at least 5 radiation lengths of material for normal incidence of the π^0 photons. Photography of the spark arrays associated with showers in the chambers was accomplished with a complex array of mirrors that brought 12 views (two stereoscopic views for each chamber) onto a format comprising a single frame in a camera field.

The camera employed could recycle and take successive pictures at intervals of about 100 msec. With this equipment we were able to secure a photographic rate of typically five or six events per beam pulse of the Bevatron when the Bevatron was being operated at optimum conditions for this experiment. Much of the run time, however, was devoted to a shared use of the Bevatron in which both this experiment and a bubble-chamber experiment were accommodated; under that condition about two events per Bevatron pulse could be photographed.

During the experiment, now completed, about 500 000 events were photographed. The data-reduction task is beginning.

STUDY OF INELASTIC π^-p COLLISIONS IN THE RESONANCE REGION

At the same time that the run described in the previous section was accomplished, another experiment, also addressed to the problem of understanding the resonance phenomena in the pion-nucleon interaction, was done in the same beam, but with a separate hydrogen target. This experiment was designed to identify the behavior of reactions producing a single additional pion in the final state. We thus studied the two reactions

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

and

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

This particular effort was to identify the role of final-state interactions in controlling the behavior of the π^-p cross section in the region of the resonance phenomena. The two final-state systems believed to possibly exert a dominant influence are (a) the ρ meson, in which form the $\pi^+\pi^-$ pair could emerge, and (b) the nucleon isobar, in which form the π^-n combination could emerge, as could also, with smaller effect, the π^-p and π^0p combinations. In order to identify these final-state systems an array of spark chambers and a magnetic spectrograph were employed to study the momenta of the outgoing charged particles and to make a complete kinematical determination of the final state. Also, for part of the experiment, a neutron-detecting system employing flight-time determination to specify the neutron energy was utilized. This experiment has also terminated within the last few days and its data have been surveyed far enough only to indicate the evidences for the final-state interactions anticipated. A study of their behavior as a function of incident pion energy will be forthcoming as the total data of the experiment are analyzed. As a final step in this experimental program a combination of the neutron counters with time-of-flight information, and the complete spark-chamber enclosure of the charge-exchange experiment, has

been made. This arrangement is set up so as to identify the production of η^0 mesons and to observe their decay, particularly in the two π^0 mode. This last portion of the experiment is still in progress, and is intended to reveal the angular distribution effective in η^0 production in the energy region extending above threshold.

PION-PROTON SCATTERING AT SATURNE

Donald E. Hagge, Jerome A. Helland, Philip M. Ogden,
in collaboration with French physicists of the Saclay Laboratory.

In the comprehensive study of the pion-nucleon interaction to which our group has devoted its efforts over the past two or three years, we have attempted to obtain the kind of data that would allow an unambiguous specification of phase shifts in a continuous manner from the region of the well-known $3/2, 3/2$ resonance, occurring for incident pions of 200 MeV, on up in energy through the region of the resonances occurring between 500 MeV and 1300 MeV. In the course of the development of this problem it became completely clear that a detailed and consistent study of the elastic scattering was required in the energy interval between the 200-MeV resonance and the 600-MeV phenomena.

The experimental measurements involved in this study have recently been carried out by the collaboration of members of this group with physicists of the C. E. N. Laboratory at Saclay. The instrumentation employed was in large part that developed in Berkeley and shipped to Saclay for this purpose, whereas the accelerator and beam facilities were provided by the Saturne machine and its associated equipment as arranged by our French associates.

This experimental program has been carried through with apparently completely satisfactory results, and the analysis of the data is proceeding normally.

The comprehensive phase-shift calculations to be applied have been prepared over the period of the past two years and are available for the treatment of the data from this experiment as well as from those described previously involving polarization and charge-exchange information. This consists principally of the elaborate phase-shift search program developed for the 7090 computer by Robert J. Cence.

PHYSICS RESEARCH

William A. Nierenberg in charge

ATOMIC BEAM GROUP

The Atomic Beam Group continues to devote most of its effort to the systematic measurement of various atomic and nuclear properties of radioactive isotopes. The principal properties measured by this technique are nuclear spins, nuclear magnetic dipole and electric quadrupole moments, atomic hyperfine structures and hyperfine-structure anomalies, and electronic g factors. These properties serve several useful functions in atomic and nuclear theory. The nuclear constants form test information for theories of the nuclear ground state. In addition, the constants act as a basis for constructing decay schemes in β - and γ -ray spectroscopy. The atomic constants likewise help in establishing a correct and consistent picture of the ground and low-lying electronic states in free atoms.

The group's work is here represented by the changes in status that have occurred and by the publications that have appeared during the period of this report:

1. Richard Dixon Worley received his Ph. D. degree with a thesis entitled Hyperfine Structure Separation, Nuclear Magnetic Moment, and Hyperfine Structure Anomaly of Cesium-131, UCRL-10872, Sept. 1963.
2. Barbara Marie Dodsworth received her Ph. D. degree with a thesis entitled Atomic Beam Measurements of the Nuclear Spins of Copper-62 and Iron-59, and the Hyperfine Structure Separation of Copper-61 and Copper-64, UCRL-10780, June 1963.
3. A paper on two isotopes of silver has been submitted to The Physical Review for publication. Y. W. Chan, W. B. Ewbank, W. A. Nierenberg, and H. A. Shugart, The Nuclear Spins and Hyperfine Structure Separations of Silver-112 and Silver-113, UCRL-10970, August 1963.
4. An abstract has been submitted to the December 1963 Pasadena meeting of the American Physical Society. P. A. VandenBout, V. J. Ehlers, W. A. Nierenberg, and M. H. Prior, Hyperfine Structure Separations of Au¹⁹⁸ and Au¹⁹⁹. Bull. Am. Phys. Soc. (to be published).
5. One member of the group, Dr. Yua Wa (Irving) Chan, has gone to Brookhaven National Laboratories to assume a postdoctoral position there.

PHYSICS RESEARCH

Wilson M. Powell and Robert W. Birge in charge

INTERACTION STUDIES

Experimental Study of K_{e4}^+ Decays

Powell-Birge Group in collaboration with U. Camerini, W. R. Fry, J. Gaidos, and R. H. March, University of Wisconsin, and S. Natali, Universita di Bari, Italy

Work is continuing in order to determine the decay rate of the K_{e4} mode. The entire film has now been scanned once, for both $\tau(K^+ \rightarrow \pi^+ + \pi^+ + \pi^-)$ and $K_{e4}(K^+ \rightarrow \pi^+ + \pi^\pm + e^\mp + \nu)$. A second scan for K_{e4} is in progress to determine the scanning efficiency of the first scan. A total of 65 events of the type $K^+ \rightarrow \pi^+ + \pi^- + e^+ + \nu$ has been found to date, compared with no events of the type $K^+ \rightarrow \pi^+ + \pi^+ + e^- + \bar{\nu}$.

The correlations between the decay products of the K_{e4} are also being studied.

Lambda Beta Decays

William J. Singleton

We have been analyzing the proton spectrum and angular correlations in Λ_β decay to determine the form of the decay interaction. For this purpose Monte Carlo programs have been developed to simulate beta decays (assuming different possible interactions) and to reproduce experimental biases and measurement errors. From these programs we have obtained the expected experimental spectra and angular correlations corresponding to the various interactions, i. e. scalar, tensor, vector, axial vector, and mixtures of V and A.

After selection we have 79 Λ_β decays and are now determining the resolution of such a sample to distinguish the different forms of the weak interaction.

Pion-Pion Interactions at 3.9 BeV/c

Robert W. Birge and Robert P. Ely, Jr.

We are using the FSD to measure two- and four-prong events obtained from interactions of 3.9 BeV/c π^- mesons with protons in the 72-inch hydrogen bubble chamber. To date nearly 8000 interactions have been measured, of which approximately 80% came through. Plots of the invariant masses of the pion-pion systems clearly show the ρ and the f^0 , and the immediate goal is to collect statistically significant numbers of events in the various peaks for detailed analysis.

Deuteron-Deuteron Interactions

George Gidal and Sedong Kim

We have taken 20 000 pictures of 3.69-BeV/c deuterons in the 20-inch deuterium bubble chamber at Brookhaven.

We are presently studying events of the type $D + D \rightarrow p p p \pi^-$, where two of the protons are spectators. The momentum distribution of the high-energy spectators is fitted excellently by the Fourier transform of the deuteron wavefunction, indicating the validity of the impulse approximation. These events are then $n + n \rightarrow n + p + \pi^-$ and we find they proceed almost entirely via an intermediate $N_{3/2, 3/2}^*$ state. Results of p-p scattering at the same energy also show this. We are presently measuring more events to check the single-pion exchange mechanism for this reaction.

We are also studying reactions of the type $D + D \rightarrow D p \pi^+ \pi^- n$ to search for low-energy $\pi\pi$ resonances and deuteron-like resonances. Elastic D-D scattering and other final states in which the deuterons remain bound are also being studied.

Pion-Pion Interactions in K_{e4}^+ Decay

George Gidal

The decay $K^+ \rightarrow \pi^+ + \pi^- + e^+ + \nu$ should be a sensitive way to study the low-energy $\pi\pi$ interaction because there are no other strongly interacting particles present in the final state.

Interference between $T=0$, S-wave and $T=1$, P-wave $\pi\pi$ scattering can be detected by observing the distributions in $P_{e^+} \cdot (P_{\pi^-} \times P_{\pi^+})$, the decay angle of the π^+ in the dipion center of mass, and the Q^* value of the two pions. Note that time reversal invariance requires the first distribution to be isotropic in the absence of any $\pi\pi$ interactions.¹ N. Cabbibo has calculated the expected distributions and we are presently fitting the data with the relevant parameters.

Energy Spectrum of π^+ in τ^{1+} Decay at Rest

George E. Kalmus and Anne Kernan

Film from the stopping K^+ run in Freon (C_3F_8) is being scanned for the τ^+ ($K^+ \rightarrow \pi^+ + \pi^0 + \pi^0$) decay mode.

The events were identified by the characteristic range of the μ^+ from the decay at rest of the π^+ .

So far, about 700 events have been measured.

1. E. P. Shabalin, Zh. Eksperim. i Teor. Fiz. 44, 765 (1963).

K_{μ3} Spectrum

Wilson M. Powell and Carl L. Sandler

Better statistics are being obtained on the energy spectrum of the μ^+ from the $K_{\mu 3}$ decay.¹ There is interest in this problem because with a precise determination of the μ^+ energy spectrum one can calculate the energy dependence of the form factors in $K_{\mu 3}$ decay.

We are scanning for $K_{\mu 3}$ events produced from stopping K^+ mesons in the Berkeley 30-inch heavy liquid bubble chamber filled with Freon, C₃F₈. We have accumulated 3000 $K_{\mu 3}$ events identified by the $K^+ \rightarrow \mu^+ \rightarrow e^+$ decay chain. Approximately 1500 events have been measured. The momentum of the μ^+ is obtained from its range with a mean error of 3%. Background study of τ^+ , $K_{\pi 2}$, and in-flight $K_{\mu 2}$ and $K_{\mu 3}$ events is in progress. A potential-path-length computer program is being written to correct for the number of $K_{\mu 3}$ decays that are not seen because the μ^+ stops outside the chamber.

K_{μ3} Polarization

George Gidal

The component of the muon polarization along the magnetic field of the bubble chamber is preserved. The decay electron asymmetry then measures this polarization, provided the bubble chamber liquid does not depolarize the muon. To check this we simultaneously measure the polarization of the muon from $K_{\mu 2}$ decay in flight. Meager preliminary results based on 200 $K_{\mu 2}$ events and 150 $K_{\mu 3}$ events, both groups selected for muon dip angle greater than 30°, give

$$\bar{a} = -0.42 \pm 0.20,$$

$$\bar{p} = +0.15 \pm 0.60,$$

where \bar{a} is the asymmetry parameter for μ decay integrated over the electron spectrum (this should be $-1/3$ for no depolarization), and \bar{p} is the $K_{\mu 3}$ longitudinal polarization averaged over the interval $150 < E_{\mu} < 200$ MeV.

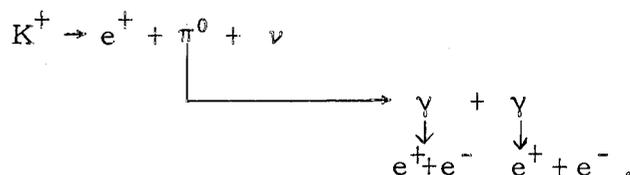
Study of $K^+ \rightarrow e^+ + \pi^0 + \nu$ Decay

Cyril Henderson, George E. Kalmus, and Anne Kernan

The purpose of the experiment is to obtain the electron and pion momentum spectra, and to study the angular correlations of the decay products.

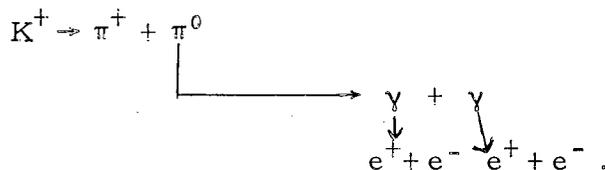
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1. J. L. Brown, J. A. Kadyk, G. H. Trilling, R. T. Van de Walle, B. P. Roe, and D. Sinclair, Phys. Rev. Letters 8, 450 (1962).

Film from the stopping K^+ run in the 30-inch bubble chamber filled with C_3F_8 is being scanned for the decay sequence



A heavy liquid chamber is advantageous for the study of this decay mode because (a) the electron is readily identified by its rapid loss of energy, and (b) the probability of γ -ray conversion is high (20% in this experiment).

In a study of this decay mode¹ it was not possible to measure the momentum of either the electron or the π^0 ; consequently, the neutrino momentum was also undetermined. In our experiment the π^0 momentum is obtained by measuring the curvature of the pair electrons in the chamber magnetic field. The Behr-Mittner formula is then used to calculate the electron momenta.² The accuracy to which π^0 momenta can be estimated by this procedure has been tested by measuring decay sequences of the type



The mean error in magnitude of the pion momentum is 5%, and the uncertainty in momentum direction is about 5 deg.

To date 300 events have been found. Scanning and measuring of the events is continuing.

This work is being done in collaboration with a group at the University of Wisconsin.

The Muonic-Decay Branching Ratio of the Lambda Hyperon

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

This experiment has been completed. An estimate of $R_\mu \leq 1 \times 10^{-4}$ has been obtained for the branching ratio $R_\mu = \frac{\Gamma(\Lambda \rightarrow p\mu^-\bar{\nu})}{\Gamma(\Lambda \rightarrow p\pi^-) + \Gamma(\Lambda \rightarrow n\pi^0)}$.

This result is based upon observation of two examples of $\Lambda \rightarrow p\mu^-\bar{\nu}$ decay

1. J. L. Brown, J. A. Kadyk, G. H. Trilling, R. T. Van de Walle, B. P. Roe, and D. Sinclair, UCRL-10205, August 1962.
2. L. Behr and P. Mittner, Nucl. Instr. Methods 20, 446 (1963).

in an effective sample of 19700 lambdas. The possibility that the two events were due to processes other than Λ_{μ} decay could not be ruled out, so that the experiment gives an upper limit for R_{μ} . The lambdas were produced by K^{-} mesons interacting in the Berkeley 30-inch heavy-liquid bubble chamber filled with a $CF_3Br-C_3H_8$ mixture.

A paper on this work has been accepted for publication.¹

This research was done in collaboration with a group at University College, London.

DATA REDUCTION

Robert W. Birge and Paul W. Weber

With a total effort of 15 (full-time equivalent) visual-measurement personnel, the following data reduction was accomplished in the past 6 months.

SCANNING			
<u>Experiment</u>	<u>Bubble chamber</u>	<u>Beam</u>	<u>Number of frames</u>
Conventional			
28	30-inch Freon	4.50-MeV/c K^{+} stopping	227 984
29	20-inch deuterium (Brookhaven)	3.69-BeV/c deuteron	9 961
30	72-inch hydrogen	3.94-BeV/c π^{-}	2 100
31	30-inch Freon	4.50-MeV/c K^{+} stopping	2 500
		Subtotal	242 545
FSD System			
30	72-inch hydrogen	3.94-BeV/c π^{-}	20 329
		Subtotal	20 329
		Total	262 874

MEASURING				
<u>Equipment</u>	<u>Measuring hours</u>	<u>Number of vertices</u>	<u>Vertices per measuring hours</u>	<u>Measuring hours per 4032 hours (%)</u>
Microscope C	199.3	836	4.2	4.9
MP-1C	1905.6	8778	4.6	47.3
Microscope E	1420.3	8799	6.2	35.2
Total	3525.2	18 413	Average 5.0	29.1

A new three-view Powell-Birge scanner was installed September 15, 1963. Two additional three-view scanners are on order and are to be delivered December 15, 1963.

1. Anne Kernan, Wilson M. Powell, Carl L. Sandler, William L. Knight, and F. Russell Stannard, Muonic-Decay Branching Ratio of the Lambda Hyperon (UCRL-11034, September 1963) and Phys. Rev. (to be published).

PAPERS PUBLISHED

1. Robert W. Birge, R. P. Ely, Jr., George Gidal, George E. Kalmus, Anne Kernan, and Wilson M. Powell (in collaboration with the University of Wisconsin), Experimental Study of K_{e4}^+ Decays, Phys. Rev. Letters 11, 35 (1963).
2. Warner Hirsch and George Gidal, K^+ -Proton Elastic Scattering at 910 MeV/c; Polarization of the Recoil Protons, University of California Radiation Laboratory Report UCRL-10950 (August 1963); also submitted to Phys. Rev.

PHYSICS RESEARCH

Emilio Segrè and Owen Chamberlain in charge

SCATTERING EXPERIMENTS WITH A POLARIZED PROTON TARGET

John Arens, Frederick Betz, Owen Chamberlain, Byron Dieterle,
Paul Grannis, Michel Hansroul, Claude Schultz, Gilbert Shapiro,
Herbert Steiner, Ludwig Van Rossum, and David Weldon

Use of a higher-frequency microwave generator together with an increased magnetic field has enabled us to attain values in excess of 60% of the polarization in our polarized target, reported in a previous Semiannual Report.¹ The target consists of a 1-inch-cube sample of $\text{La}_2\text{Mg}_3(\text{NO}_3)_{12} \cdot 24 \text{H}_2\text{O}$. The sample is kept in a helium bath at about 1.2° K in an external magnetic field of 18.5 kG, and is irradiated by 1 to 2 watts of microwave power at 70 kMc/sec. High polarizations can be maintained for several hours, and the direction of polarization can be reversed in about 10 min. Because of the large target size and the high polarizations obtained, the amplitude of the proton magnetic-resonance signal is not an adequate quantitative measure of the target polarization. A complete analysis of the Q-meter detection system must be made, and the polarization calculated accordingly.

We have measured polarization in p-p scattering at energies of 1.7, 2.85, 3.99, 5.05, and 6.15 BeV for momentum transfers between 350 and 1000 MeV/c. The Bevatron external proton beam was incident on the polarized target. The average polarization of the free protons in the target during the experiment was about ±60%. The free protons constitute 3% of the weight of the target. Kinematical separation between elastic p-p scatterings and the other more numerous interactions in the target crystal was achieved by counting both protons in coincidence. The background coincidence rate, which was always small compared with the rate of elastic scatterings, was continuously monitored and could be accurately subtracted from the data. Preliminary results indicate that the maximum polarization decreases monotonically with increasing energy from a value of +34% at 1.7 BeV to +13% at 6.15 BeV. At every energy the behavior of the polarization as a function of momentum transfer has a rather broad maximum between 400 and 800 MeV/c.

POSITRON DEPOLARIZATION IN STOPPING

R. Stiening and W. Chinowsky

An experiment is in progress to measure the depolarization of positrons being brought to rest in matter. The method of measurement of polarization is that discussed by L. Dick et al.², making use of the decay properties of positronium formed in material in a magnetic field of ≈ 18000 gauss. The apparatus has been used to measure the polarization of positrons emitted in

1. Physics Division Semiannual Report, UCRL-10862, May 1963, p. 57.
2. L. Dick, L. Feuvrais, L. Madansky, and V. L. Telegdi: Physics Letters 3, No. 7 326 (1963).

the decay of Na^{22} , yielding a result in agreement with a v/c longitudinal polarization. To provide a high-energy beam of known longitudinal polarization, positrons emitted in the decay of Cu^{64} are accelerated in a linear accelerator. With a source strength of ≈ 1 curie, there results a beam with initial intensity of $\approx 400/\text{sec}$, which decreases with the 12.8 h-half-life of Cu^{64} . The beam energy has been varied from 12 to 40 MeV. Measurements are being made to determine the dependence of the depolarization on incident-positron energy and degrader material.

ANTIPROTON ANNIHILATION IN DEUTERIUM

W. Chinowsky and G. Kojoian

The complete sample of 2100 events \bar{p} annihilation in deuterium in the 15-inch bubble chamber has been measured. Of these, 900 are $\bar{p}N$ annihilations, with approximately one-half having a visible proton spectator recoil. The spectator momentum distribution is in agreement with that expected from the Hulthén deuteron wavefunction. Of the 125 five-prong events with visible recoil, 67 were measurable with sufficient accuracy to permit the determination of the number of neutral pions in the annihilation. We find 15 ± 4 with zero π^0 , 39 ± 6 with one π^0 , and 13 ± 4 with two or more π^0 's. These numbers are not in agreement with those expected from a statistical model, nor do they agree with those to be expected if the \bar{p} -N annihilations proceeded through an intermediate state of a single-vector meson as recently considered by Berman and Oakes.³ If this were so, annihilations into an even number of pions would be forbidden. Analysis is continuing, particularly with the view toward determining the yields of vector mesons in the antiproton-neutron annihilations.

PION BETA-DECAY EXPERIMENT

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Apparatus to continue the study of rare decay modes of pions has been designed and partially constructed. Spark chambers have been incorporated into the experiment to improve the spatial resolution. The basic γ -ray detection scheme consists of two arrays of lead-scintillator-spark-chamber "sandwiches." The pions are stopped in a high-resolution spark chamber to furnish an accurate point of origin of the decay radiation.

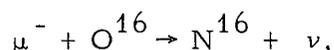
The apparatus is under test at the 184-inch cyclotron.

3. S. M. Berman, and R. J. Oakes, The Vector Theory of Strong Interactions and Antinucleon-Nucleon Annihilation, *Nuovo Cimento* 29, No. 6, 1329 (1963).

MUON CAPTURE IN O^{16}

Alan Astbury, Leonard Auerbach, David Cutts,
Robert Esterling, David Jenkins, Norman Lipman, Robert Shafer

We have measured the muon capture rate in O^{16} ,



leading to formation of the $J^P = O^-$ excited state of N^{16} . This capture rate is strongly dependent upon the induced pseudoscalar coupling constant of weak interactions.^{4,5} A quantitative evaluation of this constant now hinges on an improved knowledge of the O^{16} nuclear matrix elements. Preliminary analysis of the experimental data indicates a capture rate of $1.7 \times 10^3 \text{ sec}^{-1}$. This result can be compared to a capture rate of $0.66 \times 10^3 \text{ sec}^{-1}$ reported at Columbia University.⁶

A beam of 180-MeV/c negatively charged particles from the 184-inch cyclotron was moderated in 11.2 in. of polyethylene. This was enough moderator to stop most of the pions in the beam while moderating the muons to 110 MeV/c. The beam was then passed through a time-of-flight system that selected the muons from the electrons and pions remaining in the beam. The muons were focused by a quadrupole magnet and stopped in a water target at a rate of 240/sec. A muon that stops in the water and is captured by O^{16} will form excited states of N^{16} . A NaI crystal was located behind the water target to count γ rays from the nuclear transitions in these excited states. Any pulse that arrived in the NaI within 16 μsec of a captured muon was recorded on a pulse-height analyzer. If the muon decays into an electron, the event is vetoed by a cup counter that surrounds the water target.

Gamma rays were observed at two energies, 120 and 276. The 276-keV γ ray is emitted by a N^{16} nucleus in the transition from the 1^- (396 keV) to the O^- (120 keV) level. This γ ray is then a measure of the capture rate into the 1^- state of N^{16} . The 120-keV γ ray represents a transition from the O^- to ground state of N^{16} . The number of muons captured into the O^- state is equal to the number of emitted 120-keV γ minus the number of transitions into the O^- state from higher levels of N^{16} .

Three sets of data were taken. A 1/4-in. NaI crystal was used to look for the 120-keV gammas for 50 million stopped-muon events. To improve the detection efficiency for the 276-keV γ , a 1-in. crystal was used for 66 million stopped-muon events. Then the 276 γ -ray detection efficiency was further improved by requiring a coincidence with a 120-keV γ ray. This coincidence system was used for 150 million stopped-muon events.

This experiment was done in collaboration with members of the Crowe Group.

4. I. Duck, Nucl. Phys. 35, 27 (1962).

5. T. Ericson and J. Sens, European Organization for Nuclear Research Report No. 2184/P, 1961 (unpublished).

6. R. C. Cohen, S. Devons, and A. D. Kanaris, Phys. Rev. Letters 11, 134 (1963).

PHYSICS RESEARCH

George H. Trilling and Gerson Goldhaber in charge

K-25 EXPERIMENT

The K-25 experiment, to be performed in the new 25-inch hydrogen bubble chamber, involves a separated beam that provides K^\pm particles of momenta between 800 and 1200 MeV/c. Two runs are involved, one with K^+ to be done by our group and one with K^- to be done by the Powell-Birge group.

The new bubble chamber had a successful engineering run in November, and is expected to be ready for a physics run toward the end of January 1964. In collaboration with the Powell-Birge group, our group is developing a beam to provide K^\pm particles of either sign of charge from the same channel; we are placing in the external proton beam the target that is to be the source of the K mesons. In this way, it should be possible to shift from K^+ to K^- by merely reversing the currents in appropriate magnets. It is anticipated that such a facility should permit great flexibility, in the sense that the two runs can be interlaced, thus making possible a study of a fraction of the data from part of the run in time to influence the conditions under which the remainder of the data will be collected.

K^+ -n INTERACTIONS AT 2.3 BeV/c

We have obtained about 15 000 photographs with the Brookhaven 20-inch deuterium chamber exposed to a separated 2.3 BeV/c beam at the AGS accelerator. Technical difficulties connected with the equipment have precluded completion of the run--during which a total of 100 000 photographs will be obtained--but we expect that in the very near future this will be done.

The photographs are being scanned for K^+ -n interactions, the goal being the investigation of the $T = 0$ K-nucleon system at this high energy.

FSD ANALYSIS OF π^- -p EXPERIMENT AT 3.6 BeV/c

A comparison of hydrogen interactions of π^- mesons and π^+ mesons motivated this experiment. In particular, we have concentrated on a comparison of interactions leading to two-prong and four-prong events. So far we have successfully measured about 2000 four-prong events and 2000 two-prong events. A study of these events is now in progress.

DATA HANDLING

Howard S. White in charge

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

ACCELERATOR OPERATION AND DEVELOPMENT

BEVATRON

Edward J. Lofgren in Charge

Reports on Bevatron Operation and Development are issued on a quarterly basis. The reports to cover the period May through October 1963, are as follows: April through June, XXXVIII; July through September, XXXIX; and October through December, XL. These reports have been prepared but have not been published in final form.

184-INCH CYCLOTRON

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

The 184-inch cyclotron was used for research experiments approximately 76.5% of the time that the crew was on duty. The bulk of the outage involved a shutdown of the cyclotron for installation of the following items:

1. New meson-focusing quadrupole.
2. New thin window for meson beams.
3. Heavy-duty floor under the medical and proton cave areas.
4. New medical-beam-transport system.
5. New high-density shielding blocks for the medical and proton caves.

Descriptions of these items follow:

1. The meson-focusing quadrupole that had been in service for some years had become quite radioactive. It has to be located in an area that has the highest activity of any place within the shielding but outside of the main vacuum tank. Location of this quadrupole for the various meson beams had to be done in place because it had to be positioned manually. In addition, the need for the melting-type thermal interlocks to be reset frequently necessitated someone's going to the quadrupole. It seemed obvious, therefore, that a new quadrupole and mechanism had to be constructed to reduce the radioactive exposure of personnel.

The new quadrupole has a remotely controlled mechanism that permits the location of the magnet to be done from the control room. In addition to reducing radioactive exposure, more optimum meson beams can be generated since the quadrupole can be positioned during operation of the cyclotron.

Thermal protection for the magnet is provided by a dual system: first, mechanical-trip devices that open an electrical contact at about 90° C; and second, thermistors mounted on the coils and arranged in a circuit so that the trip point can be continuously adjusted. In addition, the thermistor circuit enables one to measure the operating temperature of each water circuit.

2. When the cyclotron was modified during 1955 to 1957, a movable, internal target for pion production was installed. The original vacuum tank was retained. After operation was resumed, it was found that one optimum position for pions to come out of the tank was a location between two ports. Consequently, an 8-in. -diameter thin window was installed at this point. During the present shutdown, the two smaller ports in the vacuum tank were made into a larger one, thus providing an uninterrupted exit for the pion beams.

3. The floor under the medical and proton caves was poured about 1941 and consisted of an unreinforced 6-inch slab of concrete. This slab had cracked and settled under the existing shielding loads used up to that time.

It was found necessary to improve the shielding by a combination of steel and heavy-density aggregate in place of the ordinary concrete blocks. Therefore, it was decided that a new heavy-duty floor would have to be poured, and it was constructed during this period.

4. A new medical-beam transport system was installed during this period. This consists primarily of a quadrupole focusing magnet, a "beam stopper," and a rotating plug with four openings, any one of which can be placed in the beam. These openings can each hold collimators of different sizes, beam degraders, etc.

This system has been reported in detail by the medical mechanical engineering department.

5. The medical cave shielding that existed up to this time was quite adequate for alpha-particle bombardment within the cave. The radiation background in the whole building, however, was too high when the full-intensity proton beam was used in the medical cave. In addition, the medical group had plans for considerable proton irradiation in connection with a contract with the National Aeronautics and Space Agency (NASA). Therefore, the shielding had to be increased. The new medical cave is now composed entirely of dense shielding. The blocks, composed entirely of heavy aggregate, are 9 feet thick. In places where space is at a premium, composite blocks constructed of 2 feet of steel plus 3 feet of heavy aggregate are used.

88-INCH CYCLOTRON

Hermann A. Grunder in charge

General Specifications

The 88-inch cyclotron meets specifications as outlined in engineering note 7330-01 M18A, except for beam-power performance. The limit in beam power is 2 kW internal beam, which results in ≈ 600 watts external beam. The limiting component is the deflector.

Operations Summary

Operating time	Hours	% of Total
Beam on	2585	59.49
Target change or adjustment	472	10.86
Subtotal	3057	70.35
Outage time		
Preventative maintenance	234	5.39
Shutdown	384	8.84
Deflector	384	8.83
Bevatron pulses	72	1.66
Misc EM/MM	214	4.93
Subtotal	1288	29.65
Total		100.00

Experimental Facilities

a. Nuclear Physics Experiments

Several experiments exploiting the variable-energy feature and good beam-energy resolution (in two caves) of the cyclotron have been completed. Others in progress include elastic and inelastic α -particle scattering from various nuclei, and detailed studies of nuclear reactions and fission induced by charged particles. The experimental result and techniques are described in the current Chemistry Division Annual Report.

b. Biophysics

The Biomedical Research Group at the 88-inch cyclotron is studying biological effects of protons and alpha particles on nerve tissue. The project, which is still in its early phase, is sponsored by NASA.

c. Nuclear Chemistry

A total of 110 targets have been bombarded for production of radioisotopes. This bombardment represents about 30% of the beam time.

Beam Development

The work of improving internal and external beams has been continued. The beams now available for experimental use are;

- 25 to 120 MeV α particles,
- 12.5 to 60 MeV deuterons,
- 10 to 50 MeV protons.

In addition, α particles of ≈ 130 MeV and protons of ≈ 60 MeV have been deflected, but difficulties in holding the deflector gradient have prevented their use by experimenters. Information such as phase-shift diagrams, extraction efficiencies, and virtual source positions has continuously been collected on various beams.

Equipment is now available to measure the radial virtual source position routinely. The spread of the radial virtual source positions over the whole energy range in beam direction is 3 in., with a reproducibility of ≈ 1 in. The spread of the transverse radial virtual source position over the energy range is 1.1 in., with a reproducibility of 0.1 in.

A phase-probe measurement with a counter was taken of particles scattered from a foil in the external beam. Thus it was possible to observe individual rf pulses (≈ 10 Mc). Except for the width of the pulses, more detailed information could not be obtained.

Critical Components

a. Deflector

The beam-power limitation has been increased for routine operation from 1 kW to 2 kW by slanting the nose of the deflector.

b. Quadrupole 1

The shift of the magnetic center of the first quadrupole has been measured to ≈ 0.05 in. in each element owing to the fringe field of the main magnet. This represents a 2-in. shift of the 120-MeV α beam at the entrance of the switching magnet. By altering the support and adding magnetic shielding, the effect has been greatly reduced.

Mechanical and Electrical Work

The shielding door for the HLC (high-level cave) has been completed. The telescope setup for observing the deflector septum has been improved. Various power supplies have been converted to SCR (silicon-controlled rectifiers). A number of rf modifications, including pre-exciter fault detector and modulator crowbar, have been done to improve reliability. A tube tester for the main oscillator tube (6949) has been built.

HEAVY-ION LINEAR ACCELERATOR

Albert Ghiorso in charge

Reported by Edward L. Hubbard

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

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