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**PHYSICS DIVISION SEMIANNUAL REPORT**

**May through October 1964**

**Berkeley, California**

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GENERAL PHYSICS RESEARCHPHYSICS RESEARCH

Luis W. Alvarez in charge

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

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 C. Doyle (JCD), Philippe Eberhard (PE), Stanley M. Flatte (SMF), Jerome Friedman (JF), 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), Darrell O. Huwe (DOH), Laurance D. Jacobs (LDJ), George R. Kalbfleisch (GRK), Janos Kirz (JK), Ronald D. Levine (RDL), James Lindsey (JL), Lester J. Lloyd (LJL), Gerald Meisner (GM), Deane Merrill (DM), Donald H. Miller (DHM), James R. Morris (JRM), Joseph J. Murray (JJM), LeRoy R. Price (LRP), Alan Rittenberg (AR), Arthur H. Rosenfeld (AHR), Ronald R. Ross (RRR), Joseph A. Schwartz (JAS), Arnold J. Schwemin (AJS), Leo Seidlitz (LS), Janice B. Shafer (JBS), Frank Shively (FS), Daniel Siegal (DMS), Gerald A. Smith (GAS), Robert G. Smits (RGS), Frank T. Solmitz (FTS), M. Lynn Stevenson (MLS), Robert D. Tripp (RDT), Robert D. Watt (RDW), Charles G. Wohl (CGW), Peter Wohlmuth (PW), and Stanley G. Wojcicki (SGW).

Humphrey, Ross, Solmitz, and Lloyd have been involved in the development of new film-measuring devices, the SMP and Spiral Reader.

## RESEARCH WITH BUBBLE CHAMBERS

Associated-Production Experiment (72-Inch Chamber)Strange-Particle Production by  $\pi^-p$  and  $\pi^+p$ 

The study of the reactions  $\pi^- + p \rightarrow \Lambda + K^0$ ,  $\pi^- + p \rightarrow \Sigma^- + K^+$ , and  $\pi^- + p \rightarrow \Sigma^0 + K^0$  at incident  $\pi^-$  momentum of 1170 MeV/c has been completed. S and P waves were found to be sufficient to fit the angular distributions for  $\Sigma^- K^+$  and  $\Sigma^0 K^0$ , but D waves were required for  $\Lambda K^0$ . We find that the polarization of the  $\Sigma^0$  is small and consistent with zero. The use

of a generalized Michel's theorem<sup>1</sup> allowed a prediction of  $\Sigma^0$  polarization from measured  $\Sigma^-$ ,  $\Sigma^0$ ,  $\Sigma^+$  angular distributions and  $\Sigma^0$ ,  $\Sigma^+$  polarization measurements. A study of np scatterings produced by the neutrons in  $\Sigma^-$  and  $\Sigma^+$  decay, combined with the prediction of  $\Sigma^-$

1. L. Michel, Nuovo Cimento 22, 203 (1961).

polarization, should yield  $\gamma$  for the  $\Sigma^-$  and  $\Sigma^+$  decays. (RDL, JCD, JAA, FSC)

#### The Reaction $\pi^- + p \rightarrow \pi^- + p + \gamma$

We have measured and processed 12 180 two-pronged events with incident  $\pi^-$  momentum of 1030 MeV/c. We hope to be able to separate the reaction  $\pi^- + p \rightarrow \pi^- + p + \gamma$  from the reactions  $\pi^- + p \rightarrow \pi^- + p$  and  $\pi^- + p \rightarrow \pi^- + p + \pi^0$ . This separation should allow us to determine the cross section for the  $\gamma$  reaction and the effective mass spectra. We also have available approximately 2000 two-pronged events with associated  $\gamma$ -ray conversions. A preliminary analysis of all these events is under way. (JAA, LRP, FSC)

#### Eta Production

We have found 113 etas from the reaction  $\pi^+ p \rightarrow \pi^+ p \eta$  at 1170 MeV/c and 41  $\eta$ 's from the same reaction at 1050 MeV/c. In addition we have 64  $\eta$ 's from the reaction  $\pi^- p \rightarrow \pi^- p \eta$  at 1170 MeV/c. The Dalitz plots are being analyzed in order to determine the percentage of  $N^*(1238)$  production in the above reactions, and also whether there are any other resonant states present [such as  $N^*(1512) \rightarrow \eta p$ ]. The various angular distributions are being systematically analyzed in an attempt to determine the production mechanism. (RAG, LRP, FSC)

#### Eta Decay, $\eta \rightarrow \pi^+ \pi^- \pi^0$

Using our sample of 213 events, we have been fitting the Dalitz plot with various theories of final-state interactions. These theories include those of Brown and Singer<sup>2</sup> (scalar dipion) and Low and Oakes<sup>3</sup> (vector dipion). In addition, theories involving S-wave "background" mixed with the above, and also ener-

gy-dependent widths, have been fitted.

The decays of  $\tau^+ \rightarrow \pi^+ \pi^0 \pi^0$ ,  $\tau \rightarrow \pi^+ \pi^+ \pi^-$ , and  $K_2^0 \rightarrow \pi^+ \pi^- \pi^0$  have also been analyzed in terms of the above theories in order to find one theory which is consistent with all the above Dalitz plots and branching ratios. (LRP, FSC)

#### The $K_2^0 - K_1^0$ Mass Difference

Analysis is continuing on 31 events which give both the sign and the magnitude of the mass difference, and 59 events which give the magnitude alone. (The statistics will soon be increased by 10 to 20% by the inclusion of events scanned by the University of Wisconsin.) The two experiments disagree as to the magnitude. The 59 events give  $|m_2 - m_1| < 1 \times 10^{10}$  sec<sup>-1</sup>; the 31 events give  $m_2 - m_1$  positive and greater than  $1 \times 10^{10}$  sec<sup>-1</sup>. The experimental technique is essentially the same in the two experiments ( $\pi^- + p \rightarrow \Lambda + K^0$ , followed by a  $K^0$  interaction). (FSC, BBC, GM)

#### Leptonic Decays of Neutral K's

We are studying a sample of leptonic  $K^0$  decays obtained from the reaction  $\pi^- + p \rightarrow \Lambda + K^0$  at an incident  $\pi^-$  momentum of  $\approx 1$  BeV/c, in the Alvarez 72-inch chamber. All together  $2 \times 10^5$  pictures have been scanned for double and single vee events. All single lambda-decay events have been rescanned along the direction of the neutral  $K^0$  to look for additional  $K^0$  decays. The double-vee events which have a  $K^0$  leptonic decay will be used to test the  $\Delta S = \Delta Q$  selection rule for leptonic decays and to examine theories about CP violation in  $K^0$  decays. Results from part of the sample have already been published.<sup>4</sup> The complete sample has approximately three times as many events as the published portion.

### K72 Experiment (72-Inch Bubble Chamber)

The K72 experiment consists of the analysis of an exposure of the 72-inch hydrogen bubble chamber to a beam of  $K^-$  mesons of incident momenta between 1.0 and 1.7 BeV/c. The exposure, totaling 14 000 events per mb, was taken between October 1961 and June 1962. A large number of results have been published; most remaining projects should be completed shortly. These final projects have required especially detailed analysis [e.g., (b), (d)] or the measurement of large numbers of events, or both.

2. L. M. Brown and P. Singer, Phys. Rev. Letters 8, 460 (1962).
3. Robert Oakes (Stanford University), private communication to Frank S. Crawford.

#### Study of the Reaction $K^- + p \rightarrow \Lambda + \pi^+ + \pi^-$ from 1.2 to 1.7 BeV/c

A sample of events of the reaction  $K^- + p \rightarrow \Lambda + \pi^+ + \pi^-$  was selected from an exposure of the Laboratory's 72-inch hydrogen bubble chamber to a separated  $K^-$  beam of the Bevatron. Laboratory momentum of the  $K^-$  in this sample was set at six values, ranging from 1.22 to 1.69 BeV/c. A sample at lower energy was also used in part of the analysis. Dalitz plots and effective-mass distributions show that the  $\Lambda - \pi$  resonance,  $Y_1^*(1385)$ , is the dominant final state; the  $\pi - \pi$  resonance,  $\rho(750)$ ,

4. G. Alexander, S. Almeida, and F. S. Crawford, Phys. Rev. Letters 9, 69 (1962).

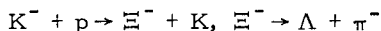
also important, has a maximum cross section at 1.5 BeV/c; and  $Y_1^*$  (1660) is produced weakly. A peak in the  $\pi$ - $\pi$  distribution can be interpreted as the electromagnetic decay,  $\omega \rightarrow \pi^+ \pi^-$ , but possible interference of this state with the  $\rho^0$  precludes a unique assignment of the branching ratio of this mode to the three-pion mode. We can set a lower limit of  $0.6 \pm 0.2$  % for this ratio, and thus establish the existence of the mode. There is also evidence of an enhancement in the  $\pi$ - $\pi$  spectrum at very low energy. We studied the angular correlations of the decay products of the  $Y_1^*$  (1385) and determined that the spin parity of this resonance is  $P_{3/2}$ , with a slight chance that it is  $D_{5/2}$ . With this spin-parity assignment, all the observed properties of the  $Y_1^*$  (1385) are consistent with assignment to a decuplet in the eightfold-way theory. There is evidence of imitation of peripheral production of  $Y_1^*$  (1385) above 1.5 BeV/c, but this process is not yet dominant at 1.7 BeV/c.<sup>5</sup> (DOH)

#### Properties of $\Xi$ Production and Decay

The analysis of  $\Xi$  production and decay is essentially complete. The cross sections for  $K^- + p \rightarrow \Xi + K (+\pi)$  have been determined from threshold (1.1 BeV/c) to 1.7 BeV/c. The  $\Xi$  spin is shown to be  $1/2$  and the decay asymmetry parameter  $a_{\Xi^-}$  is  $-0.37 \pm 0.06$ . If one writes  $\beta = \sqrt{1-a^2} \sin \phi$  and  $\gamma = \sqrt{1-a^2} \cos \phi$ , then the value of  $\phi$  is  $0.05 \pm 0.24$ . Various other decay properties have been determined, and results will soon be submitted for publication. (JPB, PE, JRH, FTS, MLS)

#### Analysis of $\Xi^-$ Decay

Approximately 750 events have been treated of the type



over an incident momentum range of 1.2 to 1.7 BeV/c. Decay distributions (the  $\Lambda$  direction and polarization) were analyzed by projecting out coefficients of spherical harmonics or the  $\mathcal{D}_{MM'}^J(\phi, \theta, 0)$  functions. Comparison of coefficients in transverse polarizations with coefficients in other distributions permitted an evaluation of the quantity  $2J+1$  and hence of the spin  $J$ . Similarly, in a parallel analysis using the maximum-likelihood method, the quantity  $2J+1$  was varied as a parameter. The spin hypothesis  $3/2$  was ruled out by about three standard deviations from a high-polarization sample containing 440 events; this sample gave rather reasonable values of the decay parameters. (Analysis of the ex-

pected distribution of the  $2J+1$  quantity was carefully done with complete treatment of error correlations.)

The results for decay parameters were the following ( $a_{\Lambda}$  taken = 0.62):

$$a_{\Xi^-} = 2 \operatorname{Re} S^* P / (|S|^2 + |P|^2) = -0.30 \pm 0.07,$$

$$\Phi_{\Xi^-} = \tan^{-1} \beta_{\Xi^-} / \gamma_{\Xi^-} = \tan^{-1} [2 \operatorname{Im} S^* P / (|S|^2 + |P|^2)],$$

$$\Phi_{\Xi^-} = 0.07 \pm 0.17.$$

(JBS, DM)

#### $K^- + p$ Interactions Around 1.05 BeV/c

The total  $K^- + p$  cross section displays a large, broad bump extending from 0.9 to 1.2 BeV/c. During the course of the K72 experiment, small exposures were made at 1.03 and 1.09 BeV/c. Total and differential cross sections have been analyzed in order to determine properties of the bump. Of particular interest are the elastic and charge-exchange channels,  $K^- + p \rightarrow K^- + p$  and  $K^- + p \rightarrow \bar{K}^0 + n$ . The total elastic cross section is 23 mb; the charge-exchange cross section is 8.2 mb. Each of these is about 6 mb larger than values above and below the region. Terms through  $\cos^5 \theta$  are necessary to adequately fit the differential cross sections. The data are analyzed in terms of a two-resonant-state model.<sup>6</sup> (CGW, SGW)

#### Decay Properties of the $\omega$ , and the Reaction $K^- + p \rightarrow \Lambda + \omega$

The characteristics of  $\omega$  decay into various channels such as  $\pi^+ \pi^- \pi^0$ ,  $\pi^+ \pi^- \gamma$ , and  $\pi^+ \pi^-$ , as well as the branching ratio into neutral modes, are being studied. The angular correlations in the process  $K^- + p \rightarrow \Lambda + \omega$ ,  $\omega \rightarrow \pi^+ \pi^- \pi^0$  have been expressed in terms of a density matrix. This approach shows that a simple exchange model for the production process is not sufficient for a full description. (PE, SF, DOH, JJM, JB-S, FTS, MLS, CGW)

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

The entire 33 000 events of the topology "zero-prong-plus-vee" found in the K72 experiment have been cleaned up, with only small corrections remaining to be made. Slightly more than half of the events are identified as  $\Lambda + \text{neutral}(s)$ . The histogram of the missing-mass spectrum for these events shows a large peak at the location of the  $\pi^0$ , a moderate amount of background, and small peaks indicating  $\eta$  and  $\omega$  production.

5. Darrell O. Huwe, Study of the Reaction  $K^+ + p \rightarrow \Lambda + \pi^+ + \pi^-$  from 1.2 to 1.7 BeV/c (Ph. D. Thesis), UCRL-11291, July 1964.

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

About 7000 of the events are identified as  $K^- + p \rightarrow \Lambda + \pi^0$ . Cross sections, angular distributions, and  $\Lambda$  polarization are being determined. The cross section decreases from about 2.3 mb at 1.05 BeV/c to 0.9 mb at 1.7 BeV/c. The angular distributions exhibit peaking in both forward and backward directions for the  $\pi^0$ , with a considerable preference for the forward direction. The  $\Lambda$  polarization varies rapidly with center-of-mass angle. (MLS, FTS, CGW, SGW)

#### The Reaction $K^- + p \rightarrow \bar{K}^0 + n$

Of the 30 000 "zero-prong-plus-vee" events between 1.2 and 1.7 BeV/c, slightly less than half are examples of  $K^- + p \rightarrow \bar{K}^0 + \text{neutral}(s)$ . About 40% of these events are charge-exchange scatterings,  $K^- + p \rightarrow \bar{K}^0 + n$ . The cross section for this reaction descends slowly from about 2.3 mb at 1.2 BeV/c to 1.7 mb at 1.7 BeV/c. The production angular distributions require terms through  $\cos^6\theta$  and  $\cos^7\theta$  for adequate fitting. A sharp backward peaking evident at 1.2 BeV/c decreases with increasing momentum, and has almost disappeared at 1.7 BeV/c. At the same time, forward peaking of the  $\bar{K}^0$  becomes the dominant feature. (CGW, MLS, FTS)

#### $\Lambda$ Interactions in Hydrogen

Work is in progress to determine cross sections and angular distributions for  $\Lambda + p$  interactions, with the  $\Lambda$  having incident momenta of 0.4 to 1.5 BeV/c. In the K72 exposure from 1.3 to 1.7 BeV/c there are 60 000 events involving a vee. About 500 of these involve a scattering or other interaction of the neutral strange particle. Preliminary results show 140  $\Lambda$  and  $\Xi^0$  interactions; the remainder are mostly  $\bar{K}^0$  events. (MHA, JRH, PW)

#### The Reaction $K^- + p \rightarrow \Sigma^\pm + \pi^\mp (+ \pi^0)$

The analysis of charged  $\Sigma$  production has been continued. Recent efforts have been directed toward enlarging the sample of events and minimizing the uncertainties due to systematic biases in determining the production cross sections. The production angular distributions for  $K^- + p \rightarrow \Sigma^\pm + \pi^\mp$  display forward peaking of the meson; this effect increases with beam momentum. In the three-body production process, resonance formation of  $Y_0^*(1405)$ ,  $Y_0^*(1520)$ , and  $Y_0^*(1660)$  are being studied. (AB-G, MHA, AHR, SGW)

#### K63 Experiment (72-Inch Chamber)

The K63 experiment to date has taken about 960 000 exposures of the 72-inch bubble chamber, with 6 to 7 incident  $K^-$  particles per picture. The momentum breakdown of the film is as follows: 68 000 exposures at 2.1 BeV/c, 74 000 at 2.45 BeV/c, 159 000 at 2.55 BeV/c, 220 000 at 2.65 BeV/c, and 133 000 at 2.70 BeV/c, all in liquid hydrogen; 66 000 at 2.1 BeV/c and 79 000 at 2.65 BeV/c, both in deuterium; and an additional 161 000 at 2.1 BeV/c in hydrogen, with lead and lead-glass plates in the chamber to convert  $\gamma$  rays. Thus far, 80 000 events have been analyzed.

#### Final-State Interactions of $\Sigma$ with Three or Four Pions

Studies of the relative production and decay rates of hyperon resonant states and meson resonances, which are manifested in  $K^- + p \rightarrow \Sigma^\pm + \pi^\mp + \pi^\mp + \pi^\mp + (\pi^0)$ , are continuing.<sup>7</sup> These include the presently known

7. J. R. Ficenec, R. I. Hulsizer, D. W. Mortara, Morris Pripstein, W. P. Swanson, and W. P. Trower, Philippe Eberhard and F. T. Shively, Reactions  $K^- + p \rightarrow \Sigma^\mp + 3\pi$  and  $\Sigma^\pm + 4\pi$  at 2.63 and 2.76 BeV/c, July 7, 1964; 1964 International Conference on High Energy Physics, Dubna, USSR.

$Y_0^*(1405)$ ,  $Y_0^*(1520)$ ,  $Y_1^*(1660)$ , and  $\rho$  and  $\omega$  mesons. Preliminary analysis confirms the existence of  $Y_1^*(1765)$ , as seen in the four-body final state. Through correlation with studies of the  $\Lambda\pi\pi(\pi)$  and  $N\bar{K}\pi(\pi)$  systems in the same exposure, branching ratios for the decay of the  $Y_1^*(1660)$  are being estimated.

Sufficient data are available to make it evident that, by proper selection criteria, relatively uncontaminated subsets of  $Y_1^*(1660)$  and  $Y_0^*(1405)$  can be obtained. Angular correlation distributions which are sensitive to the quantum numbers of these two states are constantly being studied as their statistical significance is constantly increased by the acquisition of additional data.

This research is being conducted in collaboration with a group at the University of Illinois. (PE, RRR, FS, DMS)

#### Charged Sigmas in Two- and Three-Body Final States

An incomplete set of events of the topologies which produce the final states  $\Sigma^\pm \pi^\mp$  and  $\Sigma^\pm \pi^\mp \pi^0$  have been measured for the 2.45-BeV/c film. Although no significant conclusions can be drawn from this small sample, the presence

of the known neutral hyperon resonances may be noted. It is expected that measurements on these topologies will continue more rapidly in the near future. (AB-G, PE, FS)

#### Analysis of $\Xi^-$ Decay

Decay of  $\Xi^-$  hyperons produced in the reaction  $K^- + p \rightarrow \Xi^- + K^+$ , followed by  $\Xi^- \rightarrow \Lambda + \pi^-$ , at momenta of 2.45 to 2.70 BeV/c has been studied (130 events). Coefficients of distribution of the decay  $\Lambda$ 's direction and polarization components were determined by both a projection method and a maximum-likelihood method. Spin determination through evaluation of the ratio of transverse to longitudinal polarization terms favored spin 1/2 (though less strongly than in the K72 experimental analysis).<sup>8</sup> For spin 1/2, the best estimates for the decay parameters  $\alpha_{\Xi}$  and  $\Phi_{\Xi}$  yielded by the two methods are

$$\alpha_{\Xi} = 2 \operatorname{Re} S^* P / [ |S|^2 + |P|^2 ] = -0.21 \pm 0.12,$$

$$\Phi_{\Xi} = \tan^{-1} [ 2 \operatorname{Im} S^* P / ( |S|^2 + |P|^2 ) ] = 0.62 \pm 0.30,$$

where "S" and "P" denote the amplitudes for S-wave and P-wave decay, respectively. Both the projection and the likelihood methods use the language of irreducible tensors to describe the initial  $\Xi$  spin state.<sup>9</sup> The two programs have been confirmed by treating the  $Y^*$  strong decay and comparing with earlier results, and also by treating randomly generated events from a program specially designed for these sequential decay processes. (JBS, DWM)

#### Analysis of $\Xi^*$ (1530)

Some 210  $\Xi\pi K$  events and 80  $\Xi\pi K\pi$  events were obtained at 2.45 to 2.70 BeV/c, in which the  $\Xi\pi$  system had an effective mass within the resonant peak of the  $\Xi^*$  (1530). These were analyzed with the projection method to obtain spin and parity determinations. The exclusion of spin 1/2 (fairly conclusive) and of negative parity for spin 3/2 (not conclusive) reported from UCLA<sup>10</sup> was substantially improved. New confidence limits indicated by the combination of UCLA and Berkeley K63 results are  $10^{-5}$  for spin 1/2 and  $4 \times 10^{-3}$  for  $J^P = 3/2^-$ . Additional data will be analyzed. Presently, it is considered very likely that the  $\Xi^*$  (1530)

has  $J^P = 3/2^+$  (i. e., is a  $p_{3/2}$  object). (JBS, GAS, JL)

#### Study of Additional Systems of Strangeness -2

A systematic study of the reactions  $K^- + p \rightarrow \Xi + K + \pi$ ,  $\Xi + K + \pi + \pi$ ,  $\Lambda + K + \bar{K}$ ,  $\Sigma + K + \bar{K}$ , and  $\Lambda + K + \bar{K} + \pi$  is being continued, and a resonance has been observed in the  $\Xi\pi$ ,  $\Xi\pi\pi$ , and  $\Lambda\bar{K}$  systems at 1820 MeV. This resonance has been shown to have isotopic spin  $T = 1/2$ . It has been seen in the reactions  $K^- + p \rightarrow \Xi^- + K^+ + \pi^+ + \pi^-$ ,  $\Xi^- + K^0 + \pi^0 + \pi^-$ ,  $\Xi^0 + K^0 + \pi^+ + \pi^-$ , and also in the reactions  $\Lambda + K^0 + \bar{K}^0$ ,  $\Lambda + K^+ + K^-$ ,  $\Xi^- + K^0 + \pi^+$ , and  $\Xi^- + K^+ + \pi^0$ . At present, a spin-parity assignment is undetermined. It is hoped that the final data will be sufficient to clear up questions of spin, parity, and branching ratios. Preliminary work has been published;<sup>11</sup> a final paper on the resonance and related properties will be submitted for publication soon. (GAS, JL, JJM)

#### Competing Intermediate Resonant States in the $\Lambda\pi^+\pi^0\pi^-$ Channel

During this report period a study of 1500 events of the type  $K^- + p \rightarrow \Lambda + \pi^+ + \pi^0 + \pi^-$  at 2.45 BeV/c incident  $K^-$  momentum was completed and reported at the Dubna Conference.<sup>12</sup> The study involved the writing of a FORTRAN program for estimating the amount of various resonant states present<sup>13</sup> and a program for generating Monte Carlo events to test the final estimates from the first program.<sup>14</sup> The programs are written so that they may easily be changed to extend this type of analysis to other multiparticle final states. (RRR, DMS, JHF)

#### Lambda Production in the Two-Body Final State

The excitation function and angular distributions for the reaction  $K^- + p \rightarrow \Lambda + \pi^0$  are of special interest, since the interaction must occur in the pure isospin-one state. The accumulation of examples of this process is continuing for incident momenta from 2.45 to 2.70 BeV/c, and eventually for 2.1 BeV/c. Quantitative results of sufficient statistical significance are not presently available.

8. Philippe Eberhard, Janice Button-Shafer, and Deane W. Merrill, Some Properties of the  $\Xi^-$  Hyperon, UCRL-11427 Abst., May 1964.  
9. N. Byers and S. Fenster, Phys. Rev. Letters **11**, 52 (1963).  
10. P. E. Schlein, D. D. Carmony, G. M. Perrou, W. E. Slater, D. H. Stork, and H. K. Ticho, Phys. Rev. Letters **11**, 167 (1963).

11. Gerald A. Smith and 11 others, Phys. Rev. Letters **13**, 61 (1964).

12. Ronald R. Ross and 17 others, Production of  $S=0, -1$  Resonant States in  $K^-p$  Interactions at 2.45 GeV/c, UCRL-11424 Rev., July 1964.

13. Jerome H. Friedman and Ronald R. Ross, Alvarez Programming Memo P102.

14. Daniel M. Siegel and Ronald R. Ross, Alvarez Programming Memo P103.

The proper lifetime of all  $\Lambda$  hyperons produced in the K63 exposure is being calculated. The accumulation of these data will permit a more accurate determination of the  $\Lambda$  mean life. (AB-G, FS)

#### Lambda Production with Mu or Electron Pairs

About 20 000 events of the vee + two-prong topology have been analyzed at present. Roughly 70% of these give a good fit with the vee as a  $\Lambda$ . Out of these  $\approx 1000$  have been fitted to  $\Lambda L^+ L^-$  (where "L" represents a lepton), and with our selection criteria<sup>15</sup> we are left with only 19 candidates for  $\mu^+ \mu^-$  pair and 8 for  $e^+ e^-$  pair production. These 27 events have been further investigated to establish the rates for  $\omega \rightarrow L^+ L^-$  decay and  $\phi \rightarrow L^+ L^-$  decay. The upper limits for these rates are

$$\frac{\omega \rightarrow \mu^+ \mu^-}{\text{Total } \omega} < 0.005, \quad \frac{\omega \rightarrow e^+ e^-}{\text{Total } \omega} < 0.005,$$

$$\frac{\phi \rightarrow \mu^+ \mu^-}{\phi \rightarrow K K} < 0.013, \quad \frac{\phi \rightarrow e^+ e^-}{\phi \rightarrow K K} < 0.013.$$

The analysis is still in progress, since higher statistics will be available shortly. (AB-G, RDT)

#### K<sup>-</sup>p Charge-Exchange Reaction

Cross sections and angular distributions for the charge-exchange reaction  $K^- + p \rightarrow \bar{K}^0 + n$  are being studied in the region 2.45 to 2.70 BeV/c. Preliminary results give  $\sigma = 520 \pm 70 \mu\text{b}$  at 2.45 BeV/c and  $\sigma = 300 \pm 40 \mu\text{b}$  at 2.70 BeV/c.<sup>16</sup> The angular distributions are strongly peaked forward, but do not need more than a sixth power in the cosine expansion. (AB-G, RDT)

#### Study of the 958-MeV Meson Resonance

Further studies of the 958-MeV resonance, now referred to as the  $X^0$ , have indicated that, in addition to the  $\eta 2\pi$  decay mode previously reported, a  $\pi^+ \pi^- \gamma$  decay mode exists, with the branching ratio being  $\eta 2\pi: \pi^+ \pi^- \gamma \approx 5:1$ . Forty events of the type  $K^- + p \rightarrow \Lambda + \pi^+ + \pi^- + \gamma$  in which the  $\gamma$  ray does not evidence itself in the chamber have been detected by kinematic fitting. A search for "visible"  $\gamma$  rays has been made (where "visible" means the  $\gamma$  converts to  $e e$  or Compton-scatters), and two

events have been found which fit  $\Lambda \pi^+ \pi^- \gamma$  and for which the  $\pi^+ \pi^- \gamma$  effective mass is in the  $X^0$  region. The  $\pi^+ \pi^- \gamma$  Dalitz plot indicates that the  $\pi^+ \pi^-$  are from a  $\rho$  resonance. Internal correlations among the decay products in each of the two decay modes and correlations of the  $\eta 2\pi$  system with the production particles indicate that the  $X^0$  has the quantum numbers  $TJ^{PG} = 00^{-+}$ .<sup>17</sup> The meson has a mass of  $958 \pm 1$  MeV and a full width  $\leq 7$  MeV. (GRK, OID, AHR)

#### K<sup>-</sup> Interactions in Deuterium

Scanning of the deuterium exposure at 2.1 BeV/c has begun, though no large sample of events has been measured. The exposure at 2.65 BeV/c will be scanned subsequently.

In  $K^-n$  interactions, the initial state is pure isospin  $T = 1$ , which permits a study of the  $T = 3/2$  state for the  $K\pi$  system, or  $T = 2$  for the  $Y\pi$  system. One of the objects of this work is to continue a search for resonances of higher isospin. (AB-G, JBS, OID, PE, JJM, FS, RDT)

#### K<sup>0</sup>-Meson Studies: Interaction and Decay

From the K63 exposure of the 72-inch hydrogen bubble chamber, a sampling of  $K^0 \rightarrow \pi^+ + \pi^-$  decays, from the event configurations vee + zero-, two-, or four-prongs, has been made to search for regeneration of  $K_1^0$  mesons. From the 10 000  $K_1^0$ 's used we have obtained estimates of the feasibility of further regeneration studies. We can expect more than 50 000  $K_2^0$  mesons from the entire exposure, of which one-third will have a potential time in the chamber greater than  $8 \tau_{K_1^0}$ . For this fraction it is then possible to distinguish vees resulting from regeneration or from the two-pion decay mode of the  $K_2^0$ . The average momentum of the  $K^0$ 's beyond the  $K_1^0$  background is approximately 950 MeV/c. Presently there are two events which are candidates for this category. When the sample of  $\bar{K}^0$  production is completed, it may be sufficient to test recent speculations of  $K_1^0$  regeneration from  $K_2^0$ , and the regeneration dependence on the  $K^0$  momentum, or the magnetic field component.

A more accurate determination of the  $K_1^0$  mean life will be obtained, of course, by this study. At present it is compatible with published values.

Work on events which indicate  $\bar{K}^0$  interactions with protons is in progress. (AB-G, FS)

15. Angela Barbaro-Galtieri and Robert D. Tripp, Search for  $K^- p \rightarrow \Lambda \mu^+ \mu^-$  or  $\Lambda e^+ e^-$  at 2.45 and 2.7 BeV/c Incident  $K^-$ , UCRL-11428 July 1964.

16. Angela Barbaro-Galtieri and Robert D. Tripp, The  $K^- p$  Charge-Exchange Reaction at 2.45, 2.63, and 2.70 GeV/c, UCRL-11429 July 1964.

17. George R. Kalbfleisch, Orin I. Dahl, and Alan Rittenberg, Phys. Rev. Letters 13, 349a (1964).

$\pi$ 63 Experiment (72-Inch Chamber)Resonance Production in  $K^- K_1^0 p$  and  $K_1^0 K_1^0 n$   
Final States

Increased statistics in these channels has clearly established the existence of peaks in both the  $K^- K_1^0$  and  $K_1^0 K_1^0$  effective-mass distributions at 1310 MeV. Since the widths of the peaks and distributions in momentum transfer are similar to those of the  $\pi^\pm \rho^0$  enhancement at 1310 MeV, we assume the peaks represent alternative decay modes of the same boson state. The relative rates are approximately  $K^- K_1^0: \pi^- \rho^0 + \pi^0 \rho^- = 1:6$ . The lowest spin assignment compatible with the observations remains  $J^{PG} = 2^{+-}$ . (SUC, OID, LMH, RIH, JK, DHM)

Study of  $\pi^- + d$  Interactions at 3.2 BeV/c

In order to extend understanding of the  $\pi^\pm \rho^0$  enhancement observed at 1090 MeV, the reactions  $\pi^- + d \rightarrow \pi^- + \rho^0 + p$  (p) and  $\pi^- + d \rightarrow \pi^- + \rho^0 + n$  (n) are being studied. If the 1090-MeV enhancement is observed in the  $\pi^- \rho^0$  system but not in  $\pi^- \rho^-$ , we may conclude that the effect cannot be ascribed to the Peierls mechanism, but may result from an  $I = 1$  resonant state. If the peak also occurs in  $\pi^- \rho^-$ , the ratio  $\pi^- \rho^0 / \pi^- \rho^-$  should permit a decision between an  $I = 2$  resonant state or an effect resulting from the Peierls mechanism. (Theorists have assured us that a Peierls-

mechanism origin for the effect is impossible.) (OID, DHM, LS)

The Reactions  $\pi^- + p \rightarrow \rho^0 + n$  and  $\rho^- + p$ 

Continuing interest in these reactions has been assured by the suggested structure in the  $\rho$  meson observed in several recent experiments. Further data are being accumulated in order that a detailed study of the effective-mass distributions and angular correlations through the  $\rho$ -meson mass interval may be carried out at low momentum transfer. (OID, LDJ, DHM)

Associated-Production Reactions

A large portion of the available data has been systematically analyzed in the region of the  $I = 1/2$   $\pi$ -N resonance at 2190 MeV. Although no marked structure was observed in the  $\Sigma^- K^+$  channel, the data suggest that the  $\Lambda K^0$  final state may provide a technique for determination of the quantum numbers of this resonant state. The accessibility of the  $\Lambda$  polarization in this study was particularly important. Although not conclusive at present, the data showed a significant change in angular distributions and polarizations in the resonance region consistent with the presence of a resonant amplitude of  $J = 9/2^+$ , interfering with a smooth background. Other spin-parity assignments for the resonant state, though less probable, could not be rejected. (JAS)

## DATA REDUCTION OPERATIONS

Personnel (Alvarez Scanning and Measuring Group)

The group averaged 78.07 full-time equivalents over the period May 1, 1964 through October 31, 1964. The maximum reached was 85.96 in August. Approximately 88% of each of these figures represents effort; sick leave, vacation, etc., make up the remaining 12% in each case.

Scanning

Film from the 72-inch hydrogen bubble chamber was scanned according to the following breakdown:

Experiment	Scan and event type	Number of events
APE	Scanning and Measuring on SMP $\pi^-$ 1.03 MeV/c (ET 11)	12 180
	Scan for comparison of scan-sheet vs tape-recorder methods of recording* $\pi^-$ 1.03 BeV/c (All ET's)	(16 rolls)
	Scan along projected neutron cone for recoils $\pi^+$ 1.17 BeV/c (ET 90)	525
	$\pi^-$ at 1.035 BeV/c (ET's 30 and 40)	1 000
	$\pi^-$ at 1.03 to 1.27 BeV/c (ET's 26, 36, 47)	300

\* In an effort to increase our efficiency in the use of limited personnel, we explored several new methods of recording scanning information. This method, using a tape recorder in place of a scan sheet, increased the rate for scanning a roll of 72-inch bubble chamber film by at least a factor of 2, more often 3. The accuracy was consistent with that of the older method.

We plan to continue exploring this new technique beyond its limited use to date with film having high event density.

Measuring

There were no new pieces of measuring equipment added to our production inventory of 5 SMP's, 4 Mark II Franckensteins, and 1 Spiral Reader.

The following list gives the production by machine:

Franckenstein measuring projector	Number of events measured	Number of hours of measuring
MPIIA	12 130	2 367
MPIIB	28 279	3 540
MPIIC	19 456	3 045
MPIID	29 947	3 279
Total with Franckensteins	89 812	12 231
SMP 1	8 897	1 242
SMP 2	18 905	1 745
SMP 4	14 582	1 657
SMP 5	12 587	1 454
SMP 6	17 741	1 807
Total with SMP's	72 712	7 905
Grand total	162 524	20 136

A detailed report on the performance of the SMP in measuring 40 000 of the 72 712 measured events was submitted to the Dubna Conference.<sup>18</sup> The average measuring rate for the period was 9.2 events per measuring hour. There are still some classes of events (short  $\Sigma$ 's in particular) which are difficult to measure on the SMP and are currently measured on Franckensteins. Changes in the software and the hardware (see SMP Development) have been designed to alleviate this situation.

The Spiral Reader, although included in our inventory of measuring machines, underwent extensive modification during this period. The 1700 events measured were for testing purposes.

18. W. E. Humphrey and R. Ross, Operation of the SMP Data-Analysis System, UCRL-11425 Rev., June 22, 1964.



## DATA-REDUCTION DEVELOPMENT

SMP DevelopmentProgramming Developments

Three main areas have been covered by program developments.

1. Changes in the operating executive program made on a day-to-day basis to increase effectiveness of current operation

We now are operating 5 SMP's on-line to the IBM 7040 computer. The program has been changed to handle 18 constants for the removal of optical distortion due to the SMP projection system. Various small changes were made to decrease the number of "program stops" which took the entire system out of operation.

2. Major design changes in the operating programs

A new version of the executive program was made to permit the determination of vertex points from the intersection of measured tracks. The vertex point was previously determined by a separate measurement. This new version of the program is still in the process of development and test. The main problem is to insure the accuracy of the resulting vertex-point determination for the wide range of input data available from track measurements on the SMP.

Development of a first-order spatial reconstruction program has started during this period. The program will test the event as a whole before sending it on to the processing programs.

The filtering program TRACK is being studied with an eye to future improvements for short tracks and vertex-determining data.

3. Auxiliary Programs

Programmers' Memo P-83 has now been implemented by the diagnostic program GHOSTIC. This program operates with the current executive program and can be used by

maintenance to debug a single SMP while others continue to measure normally. Memo P-83 revised describes the present state of the program GHOSTIC.

A new calibration program has been developed to allow for more parameters in correcting the distortions due to the SMP projection system. The system element most needing the new corrections was found to be the ceiling mirror.

Hardware Development

Numerous minor electronic and mechanical changes have been made on the SMP's in the past six months to increase their measuring rate and decrease down time for maintenance.

New and better lenses have been tested for the SMP projection system. Electronics to make possible single-point measurements on the SMP has been designed and tested on one machine. This mode of operation will be used in future software developments by means of a character function code. The SMP can be switched from the normal to point-measuring mode and back again by computer control.

The most serious maintenance problems are with the typewriters and the x-y axis scaling system (coarse digitizers). Circuits to slow down the Invac typewriters and to filter out noise in their logic system have been developed. A photo switch has been designed to replace an unreliable contact in the IBM typewriters.

Sensors in the x-y scaling system (coarse digitizers) have again been changed to reduce dirt collection and to make adjustment easier.

Also, the automatic gain-control circuit has been extended in dynamic range, and its signal-to-noise ratio improved. All SMP's have been made as similar as possible both mechanically and electrically. An easier method of azimuth calibration is now in use. (RRR, WEH)

Spiral Reader Development

During the past six months a number of steps have been taken to improve the reliability, accuracy, and flexibility of the Spiral Reader system.

A video channel of improved design has been

installed and successfully operated. These improvements include an automatic gain control, with frequency response varying with the radius of the scan, and significant increase in the signal-to-noise ratio. A small digital computer, the Digital Equipment PDP-4, has

been installed as the main control element, buffer memory, and magnetic-tape controller in the system. With the installation of the PDP-4 it has been possible to reduce significantly the complexity of the electronics associated with the Spiral Reader. The operation is now monitored with an on-line CRT display channel. Programs have been written for the PDP-4 to control the operation of event measurement. It is now possible to change the sequence of measurement without the extensive hardware modifications previously required. A technique has been developed to measure fiducials rapidly without the aid of an operator and to position the film under computer control.

Programs have been written for the PDP-4 for development of the new hardware and extensive diagnosis of machine malfunctions.

In the past it has been necessary to measure a point with the precision stage at the end of each track to aid the program in finding and labeling the tracks. A program MATCH has been completed that will eliminate the necessity of these time-consuming measurements. An entirely new track-filtering program, POOH, has been written during the past six months. It is designed to be significantly faster in operation and more flexible than the previous track-filtering program FILTER. (LJL, FTS)

## PROGRAMMING EFFORT

### Personnel

The computer programs described in this report were written by the following persons:

Robert J. Harvey (in charge of the  
Programming Group)

B. F. Abington	A. D. Johnson
M. H. Alston	N. K. Joseph
J. N. Baldridge	N. R. Larsen
J. P. Berge	F. E. Leavitt
J. H. Burkhard	A. J. Lee
R. W. Casey	B. Nyman
L. J. Champomier	T. H. Oliver
B. J. Cottrell	S. J. Penny
O. I. Dahl	J. Shafer
C. T. Draper	J. D. Stedman
F. L. Hodgson	T. R. Tonisson
M. S. Hutchinson	

### General Information

Most of the programs used by the Alvarez Group for analysis of hydrogen bubble chamber data have been described in previous semiannual reports. The improvements made to the existing program, as well as the new programs written during the last 6-month period, are described below.

For the purposes of review a brief description of these programs is given. Data from the measuring projectors are processed through PANAL to check for obvious errors and re-ordered to a single format. PACKAGE does geometrical reconstruction of measured tracks and kinematical fitting of the events to various hypotheses. The WRING program compacts the PACKAGE output data. SUMX makes histograms, plots, and tabulations of the results. Finally, LINGO and LYRIC, library

programs, keep records of the events through all stages of data reduction.

### PANAL

The PANAL program was modified to read the improved direct magnetic tape format. New PANAL memos include operating instructions<sup>19</sup> and an appendix to Memo P-31.<sup>20</sup> The appendix includes flow charts and subroutine definitions. TONG,<sup>21</sup> a new program that operates on

19. N. Larsen, Operating Information - PANAL (7094 and 7044), Alvarez Programming Memo P-96, August 7, 1964.

20. M. Hutchinson, PANAL - Alvarez Group Programming Memo P-31, February 1, 1964.

21. F. Hodgson, TONG - Alvarez Programming Memo P-105, October 29, 1964.

PANAL output data, plots track data on the Cal-Comp plotter.

### PACKAGE

The PACKAGE program has been modified for the P163 deuterium experiment. These modifications include writing new event types and changes which allow a zero-length charged track to be treated as a measured track (with zero momentum) instead of missing track. New PACKAGE memos include operating instructions<sup>22</sup> and bibliography.<sup>23</sup>

### SUMX

SUMX,<sup>24</sup> the plotting program, was modified to write the user's control cards on the printer output. A 7044 FORTRAN IV version of SUMX is presently being written.

### LYRIC

LYRIC, the new FORTRAN IV library routine, is now operating on the 7044 computer. The library program maintains records for each scanned event on the master list (processing information) and data summary (physics results) tapes. Operating instructions<sup>25</sup> are available.

A 7094 version of the LYRIC program is presently being written. The input and output routines for the 7094 version have been written.

### TVGP and FIT

The test of the three-view geometry program, TVGP, using actual data, indicates the need for revising some of the routines. Routines are also being written to make TVGP a production program.

The new kinematic program, FIT, is being developed.

### SMP

The executive program, RAIDALL,<sup>26</sup> can

22. N. Larsen and C. Draper, Operating Information 7044 and 7094 PACKAGE - Alvarez Programming Memo P-93, June 17, 1964.

23. N. Larsen, PACKAGE memos and notes - Alvarez Programming Memo P-101, October 12, 1964.

24. L. Champonier, Fortran Program SUMX, UCRL-11222, May 1964.

25. M. Hutchinson, LYRIC, Alvarez Programming Memo P-99, September 3, 1964.

26. B. Abington, RAIDALL - Alvarez Programming Memo P-95, August 20, 1964.

now handle several SMP's connected to the 7040 computer. A routine, VERTCO,<sup>27</sup> has been written to eliminate the necessity of measuring vertex points. The majority of the kinematic checking subroutines for RAIDALL have been converted to the 7040 MAP language. The proposed diagnostic routines<sup>28</sup> for the SMP's have been written.

### Spiral Reader

The POOH program reduces the Spiral Reader output data to a standard format acceptable to the programs PANAL and PACKAGE. A PDP-4 computer monitors, blocks, and writes the data from the Spiral Reader.

The MATCH program<sup>29</sup> has been modified to work with the Spiral Reader. MATCH examines all track images at a preselected vertex and attempts to identify the image on each of the three views.

### MEMO, HARVST, SUM, MET

MEMO<sup>30</sup> is a 7044 program that sorts memo titles by number and author. The 7044 HARVST<sup>31</sup> program maintains scanner and maintenance records of the measuring projectors in the Alvarez Group. SUM<sup>32</sup> is a 7094 Fortran II program that plots summed functions on the CRT, Cal-Comp, and (or) magnetic tape. The 7044 program MET (measurement-error-tally) tallies machine or measurer information from measurement data on the library master list.

### Mass Storage

For the past 2 months extensive simulation studies have been made on commercially available mass storage devices. These studies will continue after the selection of a device, in order to integrate the device into the bubble chamber analysis system. The final specification for a device to meet the needs of the Laboratory will be written in the near future.

27. A. Lee, Program to Eliminate Separate Vertex Measurement on SMP's, Alvarez Programming Memo P-94, June 19, 1964.

28. W. Humphrey, SMP Diagnostic Test, Alvarez Programming Memo P-83, April 10, 1964.

29. S. Penny, MATCH, Alvarez Programming Memo P-88, June 3, 1964.

30. B. Nyman, MEMO, Alvarez Programming Memo P-91, June 10, 1964.

31. B. Nyman, HARVST, Alvarez Programming Memo P-90, June 8, 1964.

32. T. Tonisson, SUM, Alvarez Programming Memo P-86, June 26, 1964.

## BUBBLE CHAMBER OPERATION AND DEVELOPMENT

72-Inch Bubble Chamber

The  $\pi 63$  and K63 experiments continued throughout the report period. The chamber operated continuously except for a 3-week shut-down to install a lead glass and lead plate channel for the K63 experiment.

Joseph J. Murray and co-workers obtained 814 rolls of K63 film (592 in  $H_2$  and 222 in  $D_2$ ), and Donald Miller and co-workers obtained 238 rolls of  $\pi 63$  film (161 in  $H_2$  and 77 in  $D_2$ ).

The K63 experiment has also obtained 200 rolls of K film with lead glass and lead plates.

A total of  $8.3 \times 10^5$  pictures was taken during the report period.

25-Inch Bubble Chamber

The Trilling-Goldhaber and Powell-Birge  $K^+$  and  $K^-$  experiment concluded in mid-September. The Trilling-Goldhaber group obtained a total of 340 rolls of  $K^+$  film (578 000 pictures) and the Powell-Birge group obtained 397 rolls of  $K^-$  film (675 000 pictures).

A total of 476 rolls was taken with hydrogen and 261 rolls with deuterium.

Of the total of 737 rolls, 359 were taken with the chamber double-pulsing (two pulses of beam per Bevatron pulse).

Minor modifications and repairs are being made to the apparatus in preparation for the next physics run.

PHYSICS RESEARCH

Walter H. Barkas in charge

I. STRANGE-PARTICLE RESEARCH

A. Decay of  $K^+$  Mesons

Douglas E. Greiner, W. Z. Osborne, Poh-Shien Young, and Walter H. Barkas

In a systematic study of some 4000 three-prong decay events an unambiguous example of a new K-meson decay mode, the  $K_{\mu 4}$ , was found.<sup>1</sup>

The  $\tau^+$  energy spectrum is being measured in the kinetic energy range  $0 \rightarrow 20$  MeV, where emulsion is highly efficient. A preliminary sample of these events is combined with the 10- to 53.8-MeV measurement by the Powell group to produce the whole spectrum. The best linear matrix element fit was  $M = 1 - (0.242 \pm 0.018)(S_3 - S_0)$ , where  $S_3 = (P_K - P_{\pi^+})^2$  and  $S_0 = (S_1 + S_2 + S_3)/3$ , with  $\chi^2 = 6.4$  for nine degrees of freedom. A fit to the Brown and Singer<sup>2</sup> resonance model gives

$$M_{\sigma} = 360 \pm 9, \Gamma_{\sigma} = 97 \pm 8,$$

with  $\chi^2 = 8.25$  for eight degrees of freedom. These values are to be compared with the  $\eta$ -decay fit of  $M_{\sigma} = 392 \pm 9, \Gamma_{\sigma} = 88 \pm 15$ .<sup>3</sup>

The low-energy portion of the  $K_{\mu 3}$  spectrum is also in the process of being measured. The branching ratio  $K_{\mu 3}/K_{e 3}$  limits the form-factor

ratio to  $\xi = 0$  or  $-6.5$ .<sup>4</sup> On the basis of 101 events in the region 0 to 20 MeV kinetic energy we have a probability ratio  $\xi=0/\xi=-6.5 = 1800$ . The complete  $\tau$  energy spectrum is being measured in order to determine if a nonlinear matrix element is required. This sample is in the process of a second scan to determine efficiencies.

A preliminary evaluation of all the scanning efficiencies for this experiment has been carried out by use of probability theory and geometric symmetry considerations. The average efficiency of the five scanners who have participated in the area scanning was found to be 93.9%. Further study is under way on the possible ways to reduce the scanner bias, and to determine decisively the efficiency for different decay modes.

Calibrations for ionization measurements were initiated in September. The final analysis of the results will be completed soon. For determining the decay branching ratios, 658 decay events have been found in the acceptance cones. Out of these, about 300 secondaries have been followed to rest.

B.  $K^-$ -Meson Interactions

J. W. Patrick

Some further study has been made of  $K^-$ -meson interactions with complex nuclei.

1. D. E. Greiner, W. Z. Osborne, and W. H. Barkas, Phys. Rev. Letters 13, 284 (1964).
2. L. M. Brown and P. Singer, Phys. Rev. 133, B812 (1964).
3. Frank S. Crawford, Jr., Ronald A. Grossman, L. J. Lloyd, LeRoy R. Price, and Earle C. Fowler, Phys. Rev. Letters 13, 421 (1964).

Ionization measurements on hyperons which decay in flight were carried out to complete the energy spectrum. Further analysis of hyper-fragment decays was also made pursuant to investigating the mechanism of formation of hyperfragments.

4. G. L. Jensen, B. P. Roe, D. Sinclair and F. S. Shaklee, Bull. Am. Phys. Soc. 9, 34 (1964).

## II. PION RESEARCH

### $\pi^0$ Decay

Hla Shwe, Frances M. Smith, and Walter H. Barkas

The work on neutral pion decay was concluded and has been submitted for publication.<sup>5</sup> The measurements were concluded some time ago, but difficulty was encountered in evaluating

the errors. A novel approach using a "Monte Carlo" generation of electron tracks, which are statistically equivalent to real tracks, finally solved the problem.

### Range Difference Between Negative and Positive Pions

Frances M. Smith, William G. Simon, W. Z. Osborne, and Walter H. Barkas

We have completed a preliminary program undertaken to measure the difference in energy loss rate between negative and positive pions of the same momentum.

The emulsion exposures analyzed were made in November 1963. The experiments were briefly described in the preceeding report.

The results in normal emulsion show a range

excess of  $\pi^-$  over  $\pi^+$  amounting to  $3.10 \pm 1.12$  microns for mesons of 95.7  $\mu$  average range.

The emulsions stopping the particles after traversing thin Au foils give some indication of the same effect. However, the uncertainty in the momentum of the particles as they enter the emulsion makes the statistics poor. For this reason a quantitative value for the range difference in Au has not yet been obtained.

## III. SPACE RESEARCH

Harry H. Heckman

(in cooperation with George H. Nakano,  
Lockheed Missile and Space Company, Palo Alto, California)

During June 1964 we had three successful recoveries of emulsion packages from polar-orbiting satellites. Since September 1962 eighteen such recoveries have permitted us to monitor the Van Allen proton flux and its east-west asymmetry between the altitudes of 270 and 520 km in the region of the South Atlantic anomaly. Over the period of these measurements the proton flux at 65 MeV has been nearly constant, although approximately four times as great as that expected from the Explorer IV (1958) data. Emulsions placed in orbit on the day (September 23, 1963) of the largest magnetic disturbance in two years recorded a flux 35% above the average, an increase of more than three standard deviations. The flux measured a month later was normal. We are now concentrating our analysis on the proton energy spectrum, 60 to 600 MeV, recorded in

December 1963, in order to detect changes (if any) in the shape of the energy spectrum.

A paper on this work was presented to the Fifth International Space Science Symposium (COSPAR), May 12-16, 1964, and is to be published in Space Research V, 1965.<sup>6</sup>

As part of this experiment, we are carrying out a computer program (written by Victor Brady of the Mathematics and Computing Group) to study particle motion in the geomagnetic field. We are using for this calculation the Jensen and Cain 48-term expansion of the earth's field. The orbit calculations will be used to evaluate the amount of atmosphere traversed by a trapped particle during its motion around the earth as a function of its minimum mirror-point altitude.

5. Hla Shwe, Frances M. Smith, and Walter H. Barkas, The Mean Life of the Neutral Pi Meson, UCRL-10118 Rev., May 1962.

6. Harry H. Heckman and George H. Nakano, Direct Observations of Mirroring Protons in the South Atlantic Anomaly, UCRL-11409, May 1964.

## IV. INSTRUMENTATION

Harry H. Heckman

TV Track-Analyzing Microscope

During this report period significant improvement in the stable operation of this instrument has been achieved. The principal electronic modifications have been in the control logic and video processing circuits. The closed television circuit was greatly improved by thoroughly cleaning the camera and replacing the Vidicon tube.

We have found that all track-ionization parameters measured by the system are reproducible within 1 to 1.5%. It now appears reasonable that this stability will also be realized on a day-to-day basis. We are beginning an extensive program of measurements to evaluate the capabilities of this ionization-measuring instrument.

PHYSICS RESEARCH

Kenneth M. Crowe reporting

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



## THEORETICAL DIVISION

David L. Judd

### I. THEORY OF THE SCATTERING MATRIX

The S matrix refers basically to infinite times, and it is defined subject to the mass-shell constraints, which restrict the associated space-time functions to solutions of the free-wave equation. The question arises therefore whether the S matrix contains all the information needed to describe actual experience, which takes place at finite times and involves interacting particles. An analysis of this problem has been carried out. It is found that space-time correlations of the type found in macroscopic experience do inhere in the structure of the S matrix. An analysis of the measurement process shows how these correlations are impressed on temporal experience even though the S matrix used to calculate them refers to infinite times. (Henry P. Stapp)

Form factors are used to explain the electron-proton scattering experiments. As form factors are not restricted by the mass-shell constraints they would appear to be outside of a strict mass-shell S-matrix theory. It is shown, however, that the form-factor expressions represent an approximation to the complete S-matrix dispersion formulas. This approximation has a clear physical interpretation: it represents the sum of all photon-pole contributions, including both the usual direct term and indirect contributions coming from photon-pole contributions in the functions that determine the other discontinuities. The approximation represented by the form-factor expression is expected to be a good one for electron-proton interaction owing to the weakness of the electron-photon interaction and the fact that the electron interaction is dominated by the electron-photon pole term. Similar circumstances do not appear to be present in strong interactions. A preliminary analysis indicates that the form-factor equations can be used to define, in terms of the mass-shell scattering amplitudes, fields that satisfy many of the properties required by local field theory. (Henry P. Stapp)

In S-matrix theory it is necessary to determine the  $i\epsilon$  prescription for integration over physical poles. This prescription has been derived<sup>1</sup> from causality requirements

1. Henry P. Stapp, Space and Time in S-Matrix Theory, UCRL-11766, Nov. 1964.

in certain cases. It has been shown that it can be determined also from crossing properties of the S matrix. (Joseph Coster)

It has been shown that the sheet structure of certain scattering amplitudes with anomalous thresholds can be determined from physical unitarity in the crossed channel without resorting to continuation in the masses, which is hard to justify in an S-matrix approach. Work is in progress to extend the method to a general box diagram. (Joseph Coster)

The basic discontinuity equation in S-matrix theory gives in general the total discontinuity across a large number of separate cuts. Work is in progress to decompose this total discontinuity into discontinuities across individual cuts. This decomposition is needed to write down the most general dispersion relations for multiparticle processes. (Joseph Coster)

The sheet structure of the two-body scattering amplitude is being studied. In particular, we are investigating various mechanisms relevant to answering the question of whether natural boundaries, as first proposed by Freund and Karplus, can arise. One possibility of cancellation of singularities has been shown to be insufficient to prevent natural boundaries from being present.<sup>2</sup> Interest is currently centered on determining what constraints are imposed by including unitarity in crossed channels. (John Schwarz)

Topological methods are being employed to study the singularity structure of scattering amplitudes. The structure of approximate amplitudes which are written as integrals of known functions (known either by means of perturbation theory or from iterations of the unitarity formula) can be determined from a knowledge of homology groups on the Riemann surface of the integrand. Also, an attempt is being made to extend these methods to investigate the structure of amplitudes defined by integral equations, both the linear Lippmann-Schwinger equation and the

2. John H. Schwarz, On the Freund-Karplus Natural Boundary (UCRL-11755, Nov. 1964), to be submitted to Phys. Rev.

unitarity equation. (J. Finkelstein)

The analytic properties of Jost functions have been studied for the Coulomb potential. As the usual definitions for Jost functions are not applicable here, they were suitably modified. The Laplace transform solutions to the differential equation were studied directly in the S-wave case, while the higher spins were studied by using Wronskians. It was found that the customary k-plane cuts are not present and that there is an essential singularity at the origin. (Abraham Bookstein)

At sharp variance with the familiar J-meromorphy of potential scattering, relativistic collision amplitudes are characterized by the appearance of J-plane branch points; evidence dates to an optical-model nucleon-deuteron calculation by Gell Mann et al.<sup>3</sup> The equivalent Feynman diagram (too complicated to actually calculate) has been scrutinized by C. Wilkin,<sup>4</sup> me, and J. C. Polkinghorne<sup>5</sup> in the equal-mass case: the J cut is absent. The case of physical masses--and the concomitant anomalous thresholds--also seems to give no cut, thereby posing a paradox. (Mark Sharefkin)

Conventional objections to the application of Bethe-Salpeter equations to the strong-interaction realm focus on lack of crossing symmetry. Unfortunately most alternative approximation schemes share this pathology. Recent work<sup>6,7</sup> on Bethe-Salpeter-type linear, relativistic equations has led to work now in progress which attempts some quantitative discussions of this difficulty. (Mark Sharefkin)

There is by now a good agreement between the distorted-wave approximation and the sharpening of peripheral peak by competing processes, although the theory itself has not been correctly derived at high energy. It has been shown<sup>8</sup> that the main result of the dis-

3. M. Gell-Mann and B. Utgankar, Phys. Rev. Letters 8, 346 (1962).

4. C. Wilkin, Nuovo Cimento 31, 377 (1963).

5. J. C. Polkinghorne (Trinity College, Cambridge, England), private communication to Stanley Mandelstam (Lawrence Rad. Lab.)

6. R. Blankenbecler and R. Sugar, Linear Integral Equations for Relativistic Scattering (Princeton University preprint), to be published in Phys. Rev.

7. A. A. Logunov and A. N. Tavkhelidze, Quasioptical Approach in Quantum Field Theory (Dubna preprint E-1145), to be published in Nuovo Cimento.

8. R. Omnes, Final-State Interaction in the Presence of Absorption (UCRL-11601, Aug. 1964), Phys. Rev. (to be published).

torted-wave approximation can be derived by applying the dispersion theory of final-state interactions to the eigenstates of the S matrix. Some assumptions have to be made about the mean values and the variation of the eigen phase shifts that fit scattering experiments. It is valid in nuclear physics. (Roland Omnes)

It has been shown that it is always possible to find explicitly an optical potential which fits a scattering amplitude satisfying the Mandelstam assumptions. The potential can be constructed by making a series of integral transformations on the momentum-transfer discontinuity of the amplitude. In the case in which the asymptotic behavior in energy of the amplitude is given by the Regge pole hypothesis, it has been shown that, although the range of the potential [behavior  $\exp(-\mu_0 r)$ ] is constant, the size of the interaction region increases with energy, owing to the non-uniformity in energy of the asymptotic behavior of the potential as a function of distance.<sup>9</sup> (Roland Omnes)

A recent result by H. J. Borchers has been extended to show that in axiomatic field theory the function F defined by

$$F(\vec{x}_1 - \vec{x}_0, \dots, \vec{x}_n - \vec{x}_0) = \int dt_0 dt_1 \dots dt_n \phi(t_0, t_1, \dots, t_n) \times \left\langle A(t_0, \vec{x}_0), A(t_1, \vec{x}_1) \dots A(t_n, \vec{x}_n) \right\rangle_0^T$$

belongs to the space  $\mathcal{S}(\mathbb{R}^{3n})$  of Schwartz if  $\phi \in \mathcal{S}(\mathbb{R}^{n+1})$ . (David P. Ruelle)

A study of particle decays has been completed and is in process of publication<sup>10</sup> (with M. L. Goldberger). In this paper it is argued, from general principles, that the exponential "law" of particle decays does not seem to be required. (Kenneth M. Watson)

The functional formalism for representing the S matrix has been extended to include an arbitrary number of different types of particles. With the usual case of a single type of massive scalar boson, the functional formalism was used to show that an operator of the type  $\exp i\eta$  (where  $\eta$  is a Hermitian operator which when expanded in plane-wave annihila-

9. R. Omnes, Optical Model and Mandelstam Representation (UCRL-11626, Aug. 1964), Phys. Rev. (to be published).

10. M. L. Goldberger and K. M. Watson, Lifetime and Decay of Unstable Particles in S-Matrix Theory (UCRL-11785, Nov. 1964), Phys. Rev. (to be published).

tion and creation operators contains an over-all four-momentum conserving  $\delta$  function) has the correct cluster decomposition required for a physically reasonable S matrix. The second cluster property, that successive scattering processes are dominated by intermediate physical particle "poles," must be imposed as a separate condition. However, if  $\eta$  contains only a finite number of terms when expanded in plane-wave annihilation and creation operators, and hence a finite number of terms when expanded in free field operators, the second cluster property cannot be satisfied. Hence, there exists an example of a unitary operator satisfying locality conditions which violates the second cluster property. Examples of theories which satisfy this property are Feynman perturbation theory and the theory of asymptotic fields of Lehmann, Symanzik, and Zimmermann. Work is continuing on the mathematical statement of the second cluster property. (James Crichton and Eyvind Wichmann)

An investigation of essential amplitude singularities at negative integer values of complex angular momentum has been extended from the case of certain nonlocal potentials<sup>11</sup> in the nonrelativistic case, to elastic relativistic amplitudes, via use of the Bethe-Salpeter equation. The locations of such singularities for particles with spin are also being studied. (John Hutchins)

The nonrenormalizable vector interaction is studied in the framework of ladder approximation. A method of perturbation expansion is developed which by-passes the usual divergence difficulties. There are, however, some ambiguities in each step of the perturbation expansion which correspond to four-point contact interaction. A method is proposed for identifying and eliminating such terms. Finally, the convergence of the perturbation series is examined by use of the four-dimensional partial-wave expansion. (Korkut Bardakci)

An iteration method was proposed for the study of partial-wave scattering amplitudes on the basis of analyticity and unitarity. By considering the analytic properties of  $\ln S_\ell(s)$ , the physical and unphysical sheets were put on the same footing. Movements of the resonance and bound-state poles could be followed as the unitarity correction to the Born term was successively taken into account. It was shown for the one-channel problem that there exists a relationship between the total number of composite-particle poles on the two-sheeted Riemann surface and the phase change of  $S_\ell(s)$ .

11. J. V. Lepore and R. J. Riddell, Jr., Phys. Rev. Letters 10, 550 (1963).

along the left-hand cut. This relationship was used to show that the maximum number of poles can be determined from the nature of the Born term without first solving the problem completely. This work is to be published.<sup>12</sup> (Rudolph C. Hwa)

Levinson's theorem was generalized to include resonance poles in the unphysical sheets for a scattering problem involving many two-particle channels. The sheet structure and the conditions for poles on each sheet were determined. The total number of composite-particle poles on all sheets was then related to the phase change of a certain function along its left-hand cut. This work has been submitted for publication.<sup>13</sup> (Rudolph C. Hwa)

Levinson's theorem has been generalized to systems of three particles. The usual two-body result relates the number of bound states of given angular momentum to the corresponding eigen phase shifts of the S matrix. Because of disconnected diagrams the three-body S matrix does not have discrete eigen phase shifts; nevertheless it is possible to define a unitary, connected matrix which has discrete eigen phase shifts. Levinson's theorem has been given in terms of these phase shifts. The proof was carried out within the framework of the Faddeev equations by generalizing Jauch's proof for two-body systems. (Jon Wright)

An investigation has been undertaken to ascertain whether the partial-wave analyticity-unitarity equations (the "N/D" equations) can be formulated for three-particle systems. The main problem is that of disconnected diagrams. It appears that the problems can be solved and that equations can be formulated. It is hoped to extend the treatment to complex angular momentum, so as to be able to prove analytic properties in the J plane with three-particle intermediate states. (S. Mandelstam)

A special model has been investigated to see if it is possible to extend the three-body scattering amplitude to complex values of the total angular momentum J by an integral equation with completely continuous kernel, or by extending the Fredholm solution of the Faddeev equations from integral J to complex J. This model is a helium atom with infinitely heavy nucleus, with the interaction

12. Rudolph C. Hwa, An Iteration Method in the S-Matrix Theory (UCRL-11545, July 1964), Phys. Rev. (to be published).

13. Rudolph C. Hwa, Generalization of Levinson's Theorem for All Composite Particles in a Multichannel Scattering Problem (UCRL-11625, Aug. 1964), submitted to Phys. Letters.

between electrons neglected and the Coulomb potentials replaced by a superposition of finite-range Yukawa potentials. One finds poles and cuts in  $J$  which depend not only upon the total energy but also upon the sub-energies of the electrons. Accordingly, the problems stated above have no solution. This

work has been reported,<sup>14</sup> (Victor A. Alessandrini and Roland L. Omnes)

14. Victor A. Alessandrini and Roland L. Omnes, Non-Regge Singularities in a Three-Body Model (UCRL-11617, Aug. 1964), Phys. Rev. (to be published).

## II. PARTICLE PHYSICS

The mechanism proposed several years ago by Peierls<sup>15</sup> to explain nonresonant peaks in cross sections was carefully investigated. It was concluded that the original proposal was based on a misunderstanding of the analytic structure of the  $S$  matrix and that the mechanism does not operate in any of the situations to which it has been applied. Certain special situations where a related mechanism may apply are being investigated. The dynamical origin of the dominance of resonance configuration in multiparticle final states has been studied. The existence of singular forces turns out to be essential, as also does the absence of an elementary "core" in the unstable particle. The baryon resonance phenomena are easier to understand than those for mesons, because the small ratio of pion to baryon masses provides a natural origin for the necessary singularity in the force. (G. F. Chew and F. E. Low)

With G. F. Chew a relation, in satisfactory agreement with experiment, has been found, in the Reggeized strip approximation, between the following quantities: the pion-pion total cross section at high energy, the width of the  $\rho$  divided by its mass, and the slope of the Pomeranchon trajectory at zero energy. The success of the relation may be interpreted as an agreement that (a) leading Regge trajectories dominate crossed-channel scattering at moderately high energies, and (b) crossed-channel exchange of low-lying states together with low-energy direct-channel unitarity determines direct-channel dynamics. This work has already been reported.<sup>16, 17</sup> (Vigdor Teplitz)

15. R. F. Peierls, Phys. Rev. Letters 6, 641 (1961).

16. Geoffrey F. Chew and Vigdor L. Teplitz, Total Cross Sections and Diffraction Scattering in the 10-100 GeV Range According to the Strip Approximation (UCRL-11516, June 1964), submitted to the 1964 Dubna Conference.

17. Geoffrey F. Chew and Vigdor L. Teplitz, Dynamical Evidence that Regge Poles Control Small Momentum-Transfer Scattering at High Energy (UCRL-11495, June 1964) submitted to Phys. Rev.

A Wiener Hopf resolvent kernel which plays a key role in the solution of the Reggeized strip approximation has been evaluated in a form suitable for machine computations. It has further been shown that this kernel remains finite in the limit in which the phase shift at the strip boundary goes to  $\pi/2$ . This latter result has the physical meaning that the amount of attraction available from inelastic channels above the strip boundary is limited. This work has been described.<sup>18</sup> (Vigdor Teplitz)

With D. C. Teplitz a machine program has been written to solve the  $N/D$  strip-approximation equations for real-integer and noninteger  $l$ . The program is applicable to a wide variety of problems. We have applied it to the pion-pion problem with exchange of a  $\delta$  function  $\rho$  and studied the output  $T = 0$  and  $T = 1$  Regge trajectories and residues as a function of the width of the exchanged  $\rho$ , the strip width, and the phase shift at the strip boundary. Trajectories of reasonable shape were obtained, but an exchanged  $\rho$  of the experimental width does not provide sufficient force to reproduce the direct channel  $\rho$  and Pomeranchon. This work has been reported;<sup>19</sup> a detailed description of the machine program is currently being prepared. (Vigdor Teplitz)

A machine program has been written for finding the contribution to the generalized potential from the exchange of Regge trajectories following the prescription of Chew and Jones<sup>20</sup> (as modified by Chew and Teplitz). Two properties of Reggeized  $\rho$  exchange have been found: (a) the contribution to even  $J$ -parity states is greater than that to odd  $J$ -parity states, and (b) the energy dependence

18. Vigdor Teplitz, Solution of the  $N/D$  Equation in the Strip Approximation (UCRL-11555, July 1964), submitted to Phys. Rev.

19. Doris C. Teplitz and Vigdor L. Teplitz, Numerical Solution of the Pion-Pion Strip Approximation of  $N/D$  Equation (UCRL-11594, July 1964), submitted to Phys. Rev.

20. G. F. Chew and C. E. Jones, Phys. Rev. 135B, 1030 (1964).

of the Reggeized potential is the same as that of the  $\delta$ -function-exchanged  $\rho$  potential. (Vigdor Teplitz)

The investigation described above is being continued, with consideration of additional contributions to the left-hand cut function,  $B_{\ell}^P$ , coming from the direct channel poles, and from the corners of the double spectral functions between the strips. (P. D. B. Collins, D. S. I. R. Research Fellow)

Work has continued on dynamical equations for pion-nucleon scattering. A thorough study has been made of the analytic properties of contributions from Regge poles which play the role of forces in the equations. It has been shown that such terms contain certain singularities not included in the Mandelstam representation. These singularities cannot be removed without greatly complicating the equations, but their contribution is shown to be small compared with that from the usual singularities. In addition, it has been made very plausible that the equations as formulated in the one-channel approximation give qualitatively the same results as previous un-Reggeized bootstrap calculations. (John Stack)

Work has been completed on the problem, mentioned in the preceding report, of studying whether "elementary" particles lie on Regge trajectories in theories with vector mesons. By detailed analysis of low-order perturbation terms, Gell Mann et al. have found that a spin-1/2 particle interacting with vector mesons did in fact lie on the trajectory, contrary to what had been expected. We have found a general explanation of this fact, and have shown that the particular channel in the particular theory considered by Gell Mann et al. is exceptional in this respect. We have investigated the vector-meson channel in the same theory and have found that it is not exceptional. A paper presenting the results of this work has been written.<sup>21</sup> (S. Mandelstam)

The Reggeization of the scattering amplitude of two particles with spin has been studied and the Reggeized scattering amplitudes for  $N + N \rightarrow N^* + N$  and  $\pi + N \rightarrow \rho + N$  have been obtained. Work is in progress to eliminate the kinematic singularities in the amplitude in order to calculate the residue functions, which will be accomplished by using the Chew-Teplitz approximation formula. It is hoped that the Reggeized amplitude will give a better fit of the high-energy  $N + N \rightarrow N^* + N$ .

21. S. Mandelstam, Non-Regge Terms in the Vector-Spinor Theory (UCRL-11686, Sept. 1964), Phys. Rev. (to be published).

and  $\pi + N \rightarrow \rho + N$  amplitudes then the peripheral model. (Ling-Lie Chau Wang)

A scheme for generating resonances in the direct channel of a two-body reaction due to the exchange of particles (bound states or resonances) in the crossed channels is being examined in a model theory of neutral spinless interacting particles. The crossed-channel Born terms have an  $s$  dependence due to the spins of the exchange particles, which in general is a polynomial in  $s$ . It is possible that this  $s$  dependence, being algebraic in nature, may exhibit maxima and minima, with the former corresponding to the resonances in the  $s$  channel. The partial-wave projections of these Born terms are also being examined, and it is hoped that they also show the resonant behavior without our having to solve the appropriate  $N/D$  equations. (Kwok M. Ong)

The question whether or not a low-energy resonance can actually determine the high-energy limit of the total cross section has been studied in the case of pion-nucleon scattering without any dynamical assumption other than the usual analyticity assumption for the scattering amplitude. It is assumed, however, that the total cross section approaches a finite nonzero limit in the limit as the incident pion energy approaches infinity. The result of this study indicates that the pronounced 3-3 resonance in pion-nucleon scattering actually almost determines the high-energy limit of the total pion-nucleon scattering cross section. (Masao Sugawara)

High-energy resonances are being studied to find the relation of anomalous singularities to their formation. Initial work indicates that the higher resonances--beyond the first--may be dominated by such singularities. That this should be likely is due to the distance of the resonances from the normal left-hand singularities--suggesting their role is diminished in resonance formation. (Philip Farber)

The Rarita-Schwinger formalism for spin-3/2 particles was studied with a view toward calculating lowest-order Feynman diagrams involving its interactions. The partial-wave analysis by Jacob and Wick in terms of helicity amplitudes was also studied, and the connection between helicity amplitudes and the Feynman amplitudes for lowest-order spin-3/2 interactions was obtained. The crossing matrices for these reactions, given in terms of 6-j symbols, was also studied. (Ivan Kramer)

The scalar meson "bootstrap" problem is being re-examined, with further contributions to the left-hand cut of the partial-wave

amplitude taken into account in addition to the bound-state poles and S-wave elastic discontinuities in the crossed channels, by generating the elastic part of the double spectral function.<sup>22</sup> (P. D. B. Collins, D. S. I. R. Research Fellow)

The matrix formulation of the N/D method is applied, in the static model, to the case of coupled two-particle channels containing one baryon and one pseudoscalar meson. The mass splitting of the  $P_{3/2}$  baryon decuplet is studied, as well as the effect of the  $\kappa\Sigma$  channel on the position of the 3-3 resonance and the  $\pi N$  3-3 phase shift. Artificial singularities in the  $ND^{-1}$  multichannel equations of the new strip approximation have been studied. (Shu-yuan Chu)

We have applied the Faddeev equations to the calculation of resonances in a state of three pions with the quantum numbers of the  $\omega^0$  particle. Only the kinematics is made relativistic and the pion-pion scattering amplitude which appears in the kernel of the equations is approximated by the  $\rho$  contribution alone. Two resonances are found, one of which has a mass and a width reasonably close to those of the  $\omega^0$ . The second resonance has an approximate mass of 1400 MeV. (Akbar Ahmadzadeh and Roland Omnes)

Electron-deuteron scattering is being investigated within the framework of the Lovelace-Faddeev integral equations for three-body scattering. The properties of the off-energy-shell two-body T matrices, which must be incorporated in the three-body equations, are being studied, and a computer program for the off-energy-shell two-body T matrix for a shielded Coulomb potential has been written for later inclusion in a numerical calculation of the three-body amplitudes. (Thomas R. Mongan)

Preliminary work on a field theoretic version of the Zachariasen model was undertaken in order to understand the relation between composite and elementary particles. (David G. Boulware)

An investigation of certain aspects of the peratization theory of Feinberg and Pais has been completed. It has been shown that the principal results of the theory can be obtained in a rigorous fashion and without need of a regulator mass. (E. Leader)

The dispersion theoretic approach to the two-body weak decays in which the dispersion

theory is applied to the decay matrix element defined off the energy-momentum shell, with all the particles strictly on their mass shells, has been applied to the three-body leptonic decay modes of various particles. The question has been studied of how to define the covariant decay amplitudes in the various three-body leptonic modes, and also how to define the partial decay amplitudes in which the pair of these strongly interacting particles in the state with definite total angular-momentum quantum number decays into the leptons. If the weak interaction is time-reversal invariant, then it has been shown that the partial-decay amplitudes in the pure elastic region have the phases which are the partial-scattering phase shifts for the same pair of the strongly interacting particles with the same total angular-momentum quantum number. (Masao Sugawara)

A theory has been proposed in which the strong and weak interactions control each other dynamically. This theory has been applied to various processes and, in particular, has been employed to determine the muon-electron mass ratio by studying the  $\mu - e$  decay. A preliminary result indicates that the approach is very promising. There are still ambiguities, however, in the formulation of the boundary condition, which feature is being examined presently. (Kazuhiko Nishijima)

The dispersion-theoretic treatment of Compton scattering on nucleons has been carried further. It has become clear that the  $\pi\pi$  s-wave isotopic spin-zero interaction cannot account for the discrepancy between theory and experiment for the energy variation of the differential cross section at  $90^\circ$  in the center-of-mass system. It is now believed that it will be necessary to take into account the three-particle  $\pi\pi N$  intermediate state, and an attempt is being made to do this approximately. (E. Leader)

An attempt is being made to provide a simple theoretical model for the double-pion photoproduction process

$$\gamma + p \rightarrow p + \pi^+ + \pi^-.$$

There appears to be some evidence in favor of the existence of a  $J = 1/2, I = 1/2$  nucleon isobar with a mass of about 1500 MeV, and its influence on the above process is being analyzed. It is hoped that it will be possible to utilize the results of this analysis in the Compton problem mentioned above. (E. Leader)

The results of the study of angular correlations in  $K_{e4}$  decays and their relation to the

22. P. D. B. Collins, Can a Scalar Meson "Bootstrap" Itself? (UCRL-11463, May 1964), Phys. Rev. (to be published).

determination of  $\pi$ - $\pi$  phase shifts<sup>23</sup> are now being applied to various models for the  $\pi$ - $\pi$  interaction. An investigation of the effects of the violation of time-reversal invariance on the theory of reference 9 will also be undertaken. (Alex Maksymowicz)

Nucleon and pion spectra to be expected from an incident beam of very-high-energy protons at various depths in a variety of materials are being calculated. Simple phenomenological formulas for the nucleon-nucleon scattering cross section and the pion production cross section which have been developed by George Trilling are the starting point of the calculation of the subsequent cascade processes. It is assumed that within a nucleus the scattering takes place essentially as nucleon-nucleon events, and further that the angular distribution is dominantly forward. A computer program which can be used for depths of material up to ten mean free paths is being written. (J. V. Lepore and R. J. Riddell, Jr.)

Statistical-model calculations of high-energy processes are in progress. Reasonable

23. Nicola Cabibbo and Alexander Maksymowicz, Angular Correlations in  $K_{e4}$  Decays and Determination of Low-Energy  $\pi$ - $\pi$  Phase Shifts (UCRL-11590, Aug. 1964), Phys. Rev. (to be published).

### III. PHYSICS OF THE NUCLEUS

The interpretation of measurements on rotational spectra in terms of centrifugal stretching of nuclei has been published.<sup>24</sup> [R. M. Diamond, F. S. Stephens (Chemistry) and W. J. Swiatecki]

The comprehensive investigation of the properties of rotating charged or gravitating liquid masses has been completed and is being prepared for publication. [S. Cohen (Argonne), F. Plasil (Chemistry), and W. J. Swiatecki]

A redetermination of the adjustable parameters in a nuclear mass formula, which is currently under development, was undertaken on the basis of the recent availability of a re-

24. R. M. Diamond, F. S. Stephens, and W. J. Swiatecki, Phys. Letters 11, 315 (1964).

fits to particle multiplicities in  $\pi$ -p and p-p reactions in the range 3 to 30 GeV have been found. Calculations are being continued in the attempt to improve the calculated spectra. (Graham Campbell)

Because of current interest in neutrino interactions a study was made of the reaction  $\nu + p \rightarrow \Sigma^0 + \mu^+$ . The coupling was that suggested by Cabibbo's theory of weak interactions. (J. V. Lepore and Robert Goren)

The dynamics of the gamma octet resonances ( $d_{3/2}$  meson-baryon resonances) is being analyzed on the basis of a multichannel Bethe-Salpeter equation. (P. van der Merwe)

An attempt was made to calculate a closed form for the isoscalar Clebsch-Gordan coefficients for  $SU_3$ . It succeeded for the representations which appear only once in a given direct product (1, 10,  $\bar{10}$ , and 27 for 8 by 8). However, the methods used did not give orthogonal states for the representations that occur more than once (8 and 8 for 8 by 8), hence a normalization matrix must be diagonalized before the coefficients can be presented. It was not possible to find a general expression in those cases. However, once the normalizations have been found, similar techniques should give a relatively simple expression for the recoupling coefficients. (David G. Boulware)

vised table of experimental nuclear masses.<sup>25</sup> During this calculation a number of changes were made in the fitting procedure, one of which treats the adjustment to known nuclear quadrupole moments in a more appropriate way than before. (William D. Myers)

A study of the possible stability of extremely heavy elements in the neighborhood of  $Z = 126$  and  $N = 184$  has been undertaken as a result of predictions based on a recently developed semi-empirical mass formula. Ways of forming such elements by means of heavy-ion bombardments are being investigated. (W. D. Myers and W. J. Swiatecki)

25. J. H. E. Mattauch, W. Thiele, and A. H. Wapstra, 1964 Atomic Mass Table, Nucl. Phys. (to be published).

## IV. MANY-BODY PHYSICS

A thesis (by Louis T. Klauder, Jr.) entitled "Statistical Theory of Nonlinear Effects in the Polarization of an Imperfect Gas" has been completed (UCRL-11595, July 1964). This thesis presents relatively systematic derivations of useful formulae for the electrostriction and the nonlinear polarization in a gas of neutral molecules. The derivations begin with the definitions from quantum statistical mechanics for the grand ensemble averages of the two quantities in question, and the resulting formulae are obtained by means of a method devised by A. N. Kaufman and K. M. Watson. (Louis T. Klauder, Jr.)

A microscopic calculation of the properties of liquid He<sup>3</sup> which employs thermodynamic Green's functions has been developed, and for the zero-temperature case the resulting coupled integral equations have been solved numerically on the Laboratory's IBM 7094 computer. In contrast to other calculations, the single-particle Green's functions have imaginary parts. The thermodynamic properties of liquid He<sup>3</sup> are considerably improved over those from other calculations, and in reasonable agreement with experimental values. This work is reported in a thesis (by Donald E. Beck), the title of which is "A Quantum Statistical Calculation of the Properties of Liquid Helium Three" (UCRL-11679, Sept. 1964. (Donald Beck and A. Sessler)

A simplified model is considered for the study of quenching phenomena of resonantly excited atoms by a thermal bath. The quenching rate is expressed as a time-correlation function similar to those which yield the transport coefficients. The low-density limit of this expression is being studied within the framework of a linked-diagram expansion. (B. Bezzerides)

The linked cluster expansion of transport coefficients of Montroll and Ward<sup>26</sup> has been successfully used to calculate the viscosity of a weakly coupled quantum gas and the electrical conductivity of an electron-phonon system. An attempt is now being made to apply the formalism to derive a kinetic equation for a classical plasma. (Harvey Gould)

The interacting boson system near the  $\lambda$  transition ( $T_\lambda$ ) is investigated by examining the many-body T matrix for  $T \geq T_\lambda$ . It is found that the T matrix (a) vanishes at  $T_\lambda$  for a repulsive separable potential, (b) has a pole at  $T > T_\lambda$  for an attractive separable potential, (c) has no pole at  $T > T_\lambda$  and vanishes at  $T_\lambda$  for a simple set of repulsive and

attractive separable potentials. (V. K. Wong)

A demonstration that the irreducible cluster integrals completely define the virial coefficients of the equation of state of a quantum system where Maxwell-Boltzmann statistics are appropriate has been completed and submitted.<sup>27</sup> (Sidney Putnam)

The form of the Feynman statistical propagator for spherically symmetric attractive potentials behaving as  $1/\tau$  or  $1/\tau^2$  as  $\tau$  approaches zero has been derived. Using the Feynman propagation, a steepest-descent asymptotic analysis is in progress to calculate the generalized second virial coefficient of a two-component quantum plasma including the effects of bound states. (Sidney Putnam)

Some numerical calculations on a model of nonresonant ion-atom charge exchange have been performed. The energies considered were, however, above the region where results are expected to differ qualitatively from those of the resonance case. The solution to a system of four coupled equations, derived variationally, to describe the rearrangement collision in the intermediate energy range is being carried through. (James Quong)

Studies were continued of the entropy (per unit volume)  $s(\rho)$  defined as a function of the sequence  $\rho$  of the correlation functions in classical equilibrium statistical mechanics. Considerable progress was made towards the proof that  $s(\rho)$  is linear under certain conditions. The result is relevant to the understanding of phase transitions and will be published, although probably not immediately. (David P. Ruelle)

Studies of the properties of intense beams in storage rings were carried out both analytically and with the aid of digital computation.<sup>28</sup> The work was closely correlated with the experimental program on the 500-MeV electron storage rings at Stanford University, where a variety of collective phenomena have been observed. The progress, to date, is summarized in two unpublished memoranda.<sup>29</sup> (A. Sessler)

27. Sidney Putnam, Irreducible Cluster Integral Development of the Quantum Equation of State (UCRL-11664, Sept. 1964), submitted to J. Math. Phys.

28. J. Young, Computer program BINTAC; P. Collom, Computer program CAROUSEL.

29. A. Sessler, Concerning Transverse Space Charge Effects in Storage Rings, June 17, 1964; A. Sessler, Single-Particle-Beam Interactions in the Stanford Electron Storage Rings, Sept. 16, 1964.

26. E. Montroll and J. C. Ward, *Physica* 25, 423 (1959).



Investigation of resistive instabilities of beams in particle accelerators was continued, the new results being incorporated in two reports.<sup>30</sup> (V. K. Neil and A. M. Sessler)

A review article on the optical model was completed (with A. Fetter) and is in process of publication.<sup>31</sup> A study of fluctuation effects in scattering (in collaboration with M. L. Goldberger) has just been submitted for publication.<sup>32</sup> In progress is the design of an intensity correlation spectrometer for measuring spectral line widths (in collaboration with H. W. Lewis). (Kenneth M. Watson)

The Kohn variational principle was used to

30. V. K. Neil and A. M. Sessler, Longitudinal Resistive Instabilities of Intense Coasting Beams in Particle Accelerators, UCRL-11089 (Rev.), Sept. 29, 1964; L. J. Laslett, V. K. Neil, and A. M. Sessler, Transverse Resistive Instabilities of Intense Coasting Beams in Particle Accelerators, UCRL-11090 (Rev.), Oct. 15, 1964.  
 31. A. Fetter and K. M. Watson, The Optical Model, to appear in Advances in Theoretical Physics, Vol. I (Academic Press).  
 32. M. L. Goldberger and K. M. Watson, Fluctuations with Time of Scattered Particle Intensities (UCRL-11640, Aug. 1964), submitted to Phys. Rev.

calculate p-wave phase shifts for the elastic scattering of electrons from a neutral hydrogen atom at subexcitation energies. The trial wave function was represented on a basis which simplified algebraic and numerical work. It was found that a careful treatment avoided the usual pitfalls of variational scattering calculations and gave quite accurate results (i. e., good to about a thousandth of a radian). Singlet and triplet p-wave phase shifts were tabulated and compared with other calculations. Similar calculations for s-wave and p-wave positron-hydrogen scattering were carried out and tabulated. The method and results were submitted to the Graduate Division of the University of California at Berkeley as a Ph. D. thesis.<sup>33</sup> (Robert L. Armstead)

The level shifts in  $\pi$ -mesic atoms are determined by the logarithmic derivative of the pion radial wave function evaluated at the nuclear surface. To determine this logarithmic derivative, studies have continued of the appropriate wave equations including nonlocal potentials for pions in nuclear matter. It is hoped that this will lead to a more accurate interpretation of  $\pi$ -mesic x-ray data. (C. Thomas Motterhead)

33. Robert Louis Armstead, The Variational Method in Electron-Hydrogen Scattering (Ph. D. Thesis), UCRL-11628, Sept. 1964 (unpublished).

## V. PLASMA PHYSICS

More effort has been devoted to obtaining the first correction to the second adiabatic invariant ( $\int p_{\parallel} ds$ ) of charged particle motion. This calculation was started over a year ago with Martin Kruskal, but was dropped because of its complexity. The earlier work has now been rechecked and several errors corrected. At the moment the work is about  $1/3$  complete. Recent numerical work by Siambis<sup>34</sup> in connection with design of a stable mirror-multipole plasma geometry has shown the effects of this first correction term and stimulated renewed interest in the calculation. Siambis has found the correction most important where the magnetic field lines have large torsion. (T. G. Northrop and C. S. Liu)

A collision term has been calculated for waves in a homogenous plasma. It reduces to

34. J. Siambis, Guiding Center Motion of Charged Particles in Combined Mirror-- Multiple Cusp Magnetic Field, (Ph. D. Thesis), University of California, 1964.

the standard Fokker-Planck collision term at zero frequency and infinite wavelength, and involves an error of order  $1/\log(n\lambda d^3)$ . The collision term may be evaluated explicitly by iteration, with the solution of the Vlasov equation used as a first approximation to the motion of the plasma. The resultant equation of motion (including the collision term) is then solved for the behavior of a wave in a plasma, including collisional effects. The result is then used to calculate a general kinetic equation for a plasma, including the effects of collisions on the fluctuations. (John C. Price)

Moment equations describing weak instabilities of a Vlasov plasma in a strong magnetic field have been obtained from an expansion of the exact moment equations. For finite plasma pressure the resulting equations are not closed, even for straight field lines and transverse motion. The equations form a closed set if the pressure is low and the field lines are straight. This set may be put in the simple form recently obtained by Rosenbluth

and Simon<sup>35</sup> from an expansion of the velocity distribution. A report of this work is in preparation.<sup>36</sup> (Alan Macmahon)

Attempts to construct a theoretical model

35. M. N. Rosenbluth and A. Simon, Finite Larmor Radius Equations with Nonuniform Electric Fields and Velocities, General Atomic Report GA-5013, June 19, 1964, submitted to Phys. Fluids.

to explain the experimental data of Astron are being made. The only definite result at this stage is that the theoretical and experimental results for the diffusion of the magnetic field through the vacuum tank are in good quantitative agreement. (Philip L. Morton)

36. Alan Macmahon, Finite Gyro-Radius Corrections to the Hydromagnetic Equations for a Vlasov Plasma (UCRL-11634, Aug. 1964), to be submitted to Phys. Fluids.

## VI. ACCELERATOR DESIGN STUDY

Members of the Theoretical Physics Division have continued to participate in the work of the Accelerator Planning Group that is studying the design of a 200-BeV proton synchrotron. The basic activity in this respect has been to assist, by analytical and computational investigations, in the evaluation and selection of parameters for the accelerator and its auxiliary equipment.

The major effort has been concerned with particle dynamics, in the accelerator and in the booster synchrotron that is proposed as an injector, from several points of view:

1. The design and computational test of various potentially competitive magnet arrangements that permit the inclusion of long straight sections that will conveniently accommodate radio-frequency acceleration stations and other special components of the accelerator and that will enhance the experimental utility of the instrument.
2. Detailed design and analysis of an extraction system that, through the provision of suitable nonlinear resonant fields, will permit a steady protracted beam to be brought out of the accelerator for use in the experimental area.
3. Analysis of nonlinear dynamical effects--not only in connection with the extraction method cited above, but also to establish tolerances for the alternating-gradient magnets and other components for which suitable specifications must be formulated to avoid possible beam loss from nonlinear effects.
4. Consideration of the alignment errors that may be expected to arise from surveying procedures, positioning errors, and movement of supports, in order to assess the probability distribution for the closed-orbit deviations that will result and to infer the aperture allowance that must be provided in the design to accommodate such deviations.
5. Numerical evaluation of the space-charge forces that will occur for an intense spatially extended beam within a vacuum chamber and magnet system of the dimensions presently planned, in order to achieve a

reasonable balance between the chamber aperture and the intensity that could in principle be achieved on the basis of our current understanding of the phenomena.

6. The application of available computer programs, in addition, has proven useful in other phases of the planning program, as in examining the efficiency with which injected particles can be picked up by the radio-frequency acceleration system and in providing numerical estimates for the resonant dimensions and field distributions within the ferrite-loaded radio-frequency cavities to be used for particle acceleration.

Each of the aforementioned activities has progressed materially since submittal of the previous Semiannual Report. Magnet configurations for the main accelerator ring and for the booster-ring injector have now been devised and analyzed, and appear to be favorable economically and to provide a sufficient space for the auxiliary components and the particle-handling equipment to be used with the accelerator. The specific design of the guide and focusing magnets to be used in such configurations is progressing through the very effective use of computational programs that take account of the field-dependent permeability of the magnet iron. The general design of the means for slow extraction of a beam are well in hand, and the detailed technical problems have been identified for continued study. Agreement has been obtained between analytic and computational results for the errors to be expected from the surveying and positioning procedures, and these results have been used in fixing the aperture of the accelerator. A portion of this last mentioned program has been the Monte Carlo investigation of the probability distribution for the largest excursion of the closed orbit within an accelerator, since it is this distribution that bears most directly on the aperture that must be selected to accommodate such orbit deviations. (Lloyd Smith, L. Jackson Laslett, Alper Garren, Phil Morton, and Andrew M. Sessler)

MATHEMATICS AND COMPUTING SERVICES GROUP

Kent K. Curtis

During the period of this report, members of the Mathematics and Computing Services

Group performed the following tasks for the Laboratory research groups.

Accelerator Design

AGS Field Design

The problem of determining and evaluating field properties of various ring magnet configurations (geometric and electrical) received continued attention.

Work was completed on developing an iterative procedure to find the numerical solution of a two-dimensional quasi-linear elliptic partial differential equation arising in the magnet design of the proposed alternating-gradient synchrotron. The procedure employs an approximate form of Newton's method to solve a system of nonlinear difference equations that are derived from the original differential equation. The procedure was tried for several test problems, and its convergence rate was faster than that achieved by other methods currently being used.

The code SIBYL<sup>1</sup> was used extensively for magnet configurations to which it is suited. The following improvements were made in the code: preparation and checking of input data were made easier, the calculation of total flux linkage of the coil was incorporated, and some local errors and inconsistencies were removed and better relaxation parameters were included. A report was written on preparation of data for the code.

The code LSQFIT was written to measure magnitude of quadrupole, sextupole and higher-order residuals for magnet configurations run by SIBYL.

The code TRIM<sup>2</sup> was used for asymmetric magnets and ring magnets whose coils are not aligned with the median plane. Further code development for ring magnet application (to increase efficiency of code operation) was planned.

The code TINKERTOY<sup>3</sup> was successful in

1. Described in Physics Division Semiannual Report, UCRL-11466, May 1964, p. 20.
2. Described in Physics Division Semiannual Report, UCRL-11466, May 1964, p. 20.
3. Described in Physics Division Semiannual Report, UCRL-11466, May 1964, p. 20.

solving infinite-permeability test cases, but convergence for finite permeability was very slow even though various combinations of number of iterations and relaxation factors were used. The use of a nine-point formula in the iron region produced better convergence ratios. Optional sweep procedures were programmed. (Fred Andrews, Bruce Burkhardt, Suzanne Clark, John Colonias, Paul Concus, Joe Dorst, and Judith Ng for Andrew Sessler and Charles Dols)

AGS Linac Design

The code TRIM<sup>2</sup> was used to solve some problems connected with an experiment to determine the effective dielectric constants of rings of materials inserted into coaxial cavities. For several cavity configurations of dielectric, for a series of values of dielectric constant, results were obtained from which the change in resonant frequency could be computed. For this purpose, it was necessary to write a version of TRIM which solved problems in cylindrical coordinates. Computed results agreed well with experiment for samples of known dielectric constant. (Fred Andrews for David Large)

A code, LASERI, was begun to determine electromagnetic resonant frequencies for various accelerator cavities such as wave guides, drift tube cells, and ferrite-loaded cells. The method used is one of matching Fourier coefficients for truncated series representing solutions in subregions of the cell. (Jonathan Young for L. Jackson Laslett)

The code ABRACADABRA was written, which determines eigenvalues and eigenvectors for an input matrix of up to 100 rows. The library subroutine QREIG is used to find the eigenvalues. The code has been used to determine resonant frequencies and potential values in linear cells in which the solution is independent of  $z$ , but dependent upon  $r$ . (Penelope Collom for L. Jackson Laslett)

AGS Orbit Studies

Improvement was worked out for the code

CIRCUS<sup>4</sup> by addition of new functions representing the behavior of a particle as it traverses an angle or crosses an rf gap. The code, as modified, has the facility to introduce "noise" to accommodate for random-phase jumps, and can deal with voltage misalignments at different cavities and can enter parameters which make it possible to follow the particle through transition energy. A search feature was included which determines the stability limit of the particle. (Barbara Levine for L. Jackson Laslett)

The code CAROUSEL was written, which computes radial orbits for up to 1000 particles with a Gaussian distribution of initial conditions. The differential equation of motion, which involves damping and space-charge effects, is integrated by a fixed-step Runge-Kutta process. The average particle orbit is plotted by the CAL-COMP. (Penelope Collom for Andrew Sessler)

The synchrotron design code, SYNCH,<sup>5</sup> was improved as follows:

- a. Edge-focusing effects were incorporated in the magnet calculations to allow for trapezoidal or wedge-shaped magnets.
- b. Provision was made to include magnetic-field errors or physical misalignments or both in magnet definition.
- c. Provision for nonlinear synchrotron elements was added.
- d. A facility was added to trace particle orbits through a hypothetical synchrotron.
- e. A variation of the Collins straight-section design facility was added.
- f. Various output formats were changed to increase readability.

Write-ups and copies of the code were furnished to other laboratories (CERN and Brookhaven). (James Eusebio for Alper Garren)

#### AGS Special Projects

The code ASTRAL resulted from extensively rewriting the code STELLA,<sup>6</sup> to compare surveying systems for AGS to arrive at a reasonable optimal system. ASTRAL provides for up to 100 surveying monuments. The code provides for matrix inversion by a partitioning process which is more accurate and faster than that used in STELLA. (Penelope Collom for James Braley)

A code PROBAT was written to determine

4. Described in Physics Division Semiannual Report, UCRL-11466, May 1964, p. 21.
5. Described in Physics Division Semiannual Report, UCRL-11466, May 1964, p. 21.
6. Described in Physics Division Semiannual Report, UCRL-11466, May 1964, p. 21.

the lower limit of probability of survival of an accelerator beam which is displaced because of measurement errors in positions of survey monuments. The closed-orbit errors at  $n$  azimuthal positions are obtained as a linear transformation of  $m$  monument errors. The transformation matrix may be generated by a subroutine if required. Noise may be included as an option. (Jonathan Young and Penelope Collom for Alper Garren and L. Jackson Laslett)

The code REPROBATE was written to solve the beam-survival probability problem (described under PROBAT) in two-dimensional beam displacement. (Barbara Levine for L. Jackson Laslett)

The code LASSIN was written to compute rms differential movement functions for various harmonic patterns in foundation movements. (Jonathan Young for L. Jackson Laslett)

The code SUMMAT was written to combine the effect of measured errors in a surveying procedure with the inherent properties of the accelerator, to relate the results of a surveying analysis with the expected response of the closed orbit within the accelerator. (Barbara Levine for L. Jackson Laslett)

#### AGS Utility Programs

The code FLUXPOINT was written to compute flux values at rectilinear mesh points of a rectangular region induced by sources of specified value at specified (nonmesh) points of the region, or to solve by iteration the inverse problem of determining values (restricted to nonnegative) for sources at specified points which induce measured flux values at mesh points. (Edwin Towster and Jonathan Young for William Gilbert)

The code OMNITRON was written to compute omnitron frequencies for various parameters. Frequency-vs-time graphs are plotted by use of the CAL-COMP Plotter. (Penelope Collom for Robert Smith)

The code FEFIFOFUM was written to solve a system of up to 100 linear simultaneous equations with 20 right-hand sides, using the matrix-inversion routine MATINV. (Barbara Levine for L. Jackson Laslett)

The code LASINT was written to compute potential differences on a square-array mesh due to a line charge at the origin. (Jonathan Young for L. Jackson Laslett)

The code BINTAC was written to compute for each cycle the positions, momenta, and amplitudes (vertical and horizontal) of a par-

ticle or set of particles within a storage ring. The purpose of the procedure is to determine the effects of various parameters on the stability; hence, the code provides for sets of input parameters. Provision is also made for plotting vertical amplitude vs  $n$  (the number of cycles) and for phase plots in  $z$  (vertical direction). (Jonathan Young and Ardith Kenney for Andrew Sessler)

The program IBINTG<sup>7</sup> was modified. (Anthony Schaeffer for Bob Jeanmaire)

#### 88-Inch Cyclotron

The code BAVE was written to compute average field values by means of least-square coefficients for specified currents. A table of average fields,  $B(R)$ , in gauss can be calculated at equal intervals of current over a given range. (Ardith Kenney for Frank Selph)

The code CYDOR<sup>8</sup> was revised to include an option to set the frequency for purposes of field isochronization and to improve the method of interpolating the trim-coil effects in order to achieve better results at the outer edge of the machine. (Ardith Kenney for Frank Selph)

7. Described in Physics Division Semiannual Report, UCRL-11466, May 1964, p. 22.

8. Described in Physics Division Semiannual Report, UCRL-11466, May 1964, p. 22.

The code INDBPT was written to plot on the CAL-COMP plotter the synchronous field  $B_g(R)$  and the interpolated main field,  $B(R)$ , which had already been computed by the code INDELB.<sup>9</sup>

The code GOC<sup>10</sup> was extensively modified to include the simulation of an electrostatic regenerator. The code is being used with the cyclotron deflector code, CYBOUT,<sup>11</sup> to design a new deflector system. The work of converting the code from IBM 704 symbolic language to FORTRAN IV for the IBM 7094 is nearing completion. (Herman Owens for Hogil Kim)

#### Beta-Ray Spectrometer

The code BARS<sup>12</sup> was used in the feasibility study to investigate the principle of strong focusing in beta-ray spectrometer design. It is hoped that the present configuration will lead to significant results in the near future. (Hermann Owens for Andrew Sessler)

9. Described in Physics Division Semiannual Report, UCRL-11132, Nov. 1963, p. 66.

10. Described in Physics Division Semiannual Report, UCRL-10572, Nov. 1962, p. 64.

11. Described in Physics Division Semiannual Report, UCRL-10349, May 1962, p. 45.

12. Described in Physics Division Semiannual Report, UCRL-11466, May 1964, p. 22.

### General Physics Research

#### Trilling-Goldhaber Group

Modifications were made to the EXAMIN routines PIOUS-4 and CHAOS.<sup>13</sup>

Work was begun on a program called FSDPAK, to generate PACKAGE<sup>14</sup> tapes from FSD output tapes. This was done so that FOG data may be processed by SELECT and EXAMIN.<sup>15</sup>

Conversion to FORTRAN IV of FAKE-FAMO<sup>16</sup> was completed. The tape-generating portion of this program was rewritten to produce a tape in PACKAGE tape format. The resulting output tape may now be processed by existing EXAMIN routines.

13. Described in Physics Division Semiannual Report, UCRL-11132, Nov. 1963, p. 51.

14. Described in Physics Division Semiannual Report, UCRL-10572, Nov. 1962, p. 52 and 53.

15. For a detailed description of the EXAMIN system, see Alvarez Physics Note No. 271, Revised, Dec. 1, 1961.

16. Gerald R. Lynch, Program FAKE, UCRL-10335, July 1962.

SELECT was written to select events from a PACKAGE tape corresponding to events identified by a scan card master list. Selection is based on roll number, frame number, event type, check-point mark and  $\chi^2$ . (Bert Albrecht)

A 7094 FORTRAN IV program "CHAOS3D" was written to use the CAL-COMP Plotter for displaying distributions of bubble chamber events. The display is a two-dimensional perspective of a three-dimensional array of histograms. (Noel Brown)

The READC package for FAIR FORTRAN tapes was rewritten to handle more elaborate event types in a more efficient manner.

Several new EXAMIN routines were written and some of the older routines were modified for experiments 03, 08, 23, 63, and 65. (Emmett Burns)

Work in the 20-inch bubble chamber experiment 23 moved into the EXAMIN and special job phases. Special strange-particle event-type subroutines ZET20K, ZET47K, ZET48K, ZET20P, ZET47P, and ZET48P, which con-

sist of 92 ambiguity calculations, were written into PACKAGE. Also subroutine ZET50 was written for the eight-track events in this experiment. The entire experiment was re-run through special  $\pi^+$  ambiguity calculations which were added to PACKAGE. Further re-examination of the experiment was made in subroutine ZET47 for the  $K^*$  resonance mass, refractive index variations to CONST2, and magnetic field variations to subroutine 20INH-Z in PACKAGE. The EXAMIN program  $K^+$ BEAM was modified to run on these and other problems in this experiment. The following subroutines were adapted for experiment 23: ZET48, SET20, KSET, BEAM23, ZET55, and PINTAB.

Progress continued on the 25-inch bubble chamber experiment 03 with the determination of the third, fourth, and fifth momentum range beam constants by the program  $K^+$ BEAM and the addition of these constants to CONS03 and TAPE03 in PACKAGE. Event-type coding was improved with the completion of subroutines ZET23, ZET24, and the addition of pion and proton incident ambiguity calculations to ZET26, ZET27, and ZET28. Special jobs included a  $K^*$  mass determination,  $K^0$  decay ambiguity calculations for  $K^-$  film, subroutines SET25, 25FELD and ZV3 (for zero-constraint fits) for the PACKAGE program.

Experiment 08, 25-inch bubble chamber  $K^+$ D, was brought into the production stage with the completion of four event-type subroutines, ZET25 through ZET28. Constant subroutine TAPE08 has been added to PACKAGE, and the program  $K^+$ BEAM is being used to determine constants.

The subroutines SETEVE (for check-point marks) and SETEMM (for missing-mass marks) were written to accomplish the subroutinizing and compressing of data words. These philosophies have proved effective in saving 48% of the storage requirement for event-type coding in PACKAGE. Event-type coding has thus been simplified and generalized to require only three locations of core per ambiguity and missing-mass calculation. Also subroutines KILL65, 65XSQC, and CPRINT were added for this purpose.

The subroutine EVRJ3 was written to give complete diagnostic summaries on events. A minimum mass calculation, MASMIN, was written into PACKAGE and EPC to give a selecting criterion in standard deviations for missing-mass calculations. Improvements were also made to subroutines NUTRAL (PACKAGE for two-point tracks), EXSET (EXAMIN, for stopping tracks), NXY (PANAL, x-direction switching for MPI-E and MPI-F) and SHUFFEL (PANAL, tape assignment and error comments).

Streamlining was accomplished in the area of program operation through the use of disk storage. Permanent disk storage of three core loads was obtained for both the 7094A and the 7094B for the PANAL,<sup>17</sup> PACKAGE, and EPC<sup>18</sup> production programs. Disk writing and reading subroutines, LDFWB and LDFWBL, were added to PANAL and PACKAGE; and subroutines EPCWRT, EPCLDR, and EPCALL were written for the FAP program EPC to accomplish the same purpose. These routines are combined with a two-card loader, which reads over itself, to load a program from the disk. This disk loading system has the advantages of shorter loading time, less tape unit usage, and continuous running without stops between any selection of the programs. The FAP subroutines DICRED and DICWRT<sup>19</sup> were added to the EXAMIN program  $K^+$ BEAM to give it the large amount of rapid access disk storage needed and to save data-tape passes. Subroutine CLK94B was written for PANAL and PACKAGE to internally distinguish between the two-channel 7094B and the three-channel 7094A, and to read the two different computer clocks.

The PANAL, PACKAGE, and EPC bubble chamber analysis system was made more versatile by the addition of coding to handle two new bubble chambers. The Lawrence Radiation Laboratory's 15-, 25-, and 72-inch bubble chambers and the Brookhaven National Laboratory's 20-, 30-, and 80-inch bubble chambers are all contained in the same system. The analysis system is readily modified by a group for a new experiment in any of these by putting in run constants and making measurement card formats compatible. The constants and fields for the Brookhaven 30- and 80-inch chambers were added, and subroutines SET30, SET80, and SETALL were written for PACKAGE and PANAL. This analysis system was given to groups at Illinois and LaJolla, and the appropriate parts were given to the 20-inch chamber groups at Stanford and Notre Dame as well. (James Miller)

#### Powell-Birge Group

A program BLOB was written to detect and correct faulty data cards produced by the key punch machines connected to microscopes used for measuring bubble chamber tracks. (Krehe Ritter and Myron Myers for P. Wesley Weber)

17. For a detailed description of Alvarez Group IBM 7090 Program PANAL, see UCID-1650, Nov. 1961.

18. For a detailed description of the EPC programs, see Alvarez Programming Note, P-10, "Modified EPC," by Barbara Cottrell, Oct. 23, 1962.

19. Used in conjunction with Myron Myers's DCYLM routine.

A program TABS<sup>20</sup> was greatly enlarged, revised, and rewritten in FORTRAN IV. This program accepts data from measurer's, scanner's, FSD operator's time cards, scanning cards, measurer's cards, and data from records of events processed by the bubble chamber data reduction programs FOG, CLOUDY, FAIR,<sup>21</sup> and MISST.<sup>22</sup> Output consists of weekly, monthly, and semiannual reports on personnel, machines, experiments (both measuring and scanning), and vertices processed in various stages of progression through the data reduction programs. The output is cross-classified into tables of various categories. (Krehe Ritter for P. Wesley Weber)

In the study of angular distributions, an expansion in powers of the cosine function is made for the analysis of partial waves. This is satisfactory except for the fact that in proceeding to higher orders of the cosine, the coefficients are significantly perturbed from previous low-order fits. Furthermore, this expansion does not give a clear indication of the highest-order wave contribution. The program LGLSQ was written in hopes of overcoming these difficulties by fitting angular distributions to the orthonormalized series from powers of the cosine function. (Edna Williams for Jack Sahouria)

#### Miscellaneous Physics

A FORTRAN IV program, RESON, has been written to calculate various physical characteristics, including total cross sections, forward-backward asymmetries, and  $\pi$ - $\pi$  mass spectrum, for the process  $\gamma + p \rightarrow \pi^+ + \pi^- + p$ . The model used is a two-resonance Breit-Wigner Model,<sup>23</sup> and it is hoped therewith to gain information as to the existence of a  $P_{11}$  resonance in the  $\pi\pi$  system. This model will eventually be used as input into the main computer scattering program. (Edna Williams for Elliot Leader, Theoretical Physics)

A program ROLAND was written for the 7094 in FORTRAN IV in connection with an investigation of resonances and analytic properties of three-body scattering: in particular, the problem of three pions with the quantum numbers of the  $\omega^0$  particle. The homogeneous

Faddeev equations for the three-body scattering amplitudes were solved approximately and two possible resonances were found -- one close to  $\omega^0$  and one with a higher mass. (Marjory Simmons for Akbar Ahmadzadeh, Theoretical Physics)

A program ATHOS was begun to calculate the effective atmospheric density encountered by a high-energy proton during its motion around the earth. The proton is trapped in the magnetic field of the earth, and its motion consists of oscillations between mirror points in the northern and southern hemispheres; these mirror points move slowly around the earth at roughly the same latitude. The earth's magnetic field is approximated by a 48-coefficient expansion obtained by Jensen and Cain.<sup>24</sup> The atmosphere is approximated by a model due to Harris and Priestler.<sup>25</sup> The total amount of atmosphere "seen" by the proton and the proton guiding center is obtained by integrating the atmospheric density over their respective paths. (Victor Brady for Harry Heckman, Barkas Group)

A FORTRAN II program called SCATAM was written for the analysis of elastic scattering data of strongly absorbed ions. The program is a nonlinear least-squares fit to a function defining the ratio of the elastic cross section to the Rutherford cross section in terms of partial waves. The scattering amplitudes of the partial waves were parameterized to several fitting parameters. (Claudette Ruge for Evangelos Hadjimichael, Moyer-Helmholz Group)

Kinematics calculations using Monte Carlo event generators (programs FAKE<sup>16</sup> and OWL) were carried out for various three-body states. (Mark Horovitz for M. Tin Maung and Roy Haddock, Crowe Group)

Minor modifications were made to 7094 code LABDIST.<sup>26</sup> The code was converted from FORTRAN II to FORTRAN IV. (Jerry Borges for M. Tin Maung, Crowe Group)

Final modifications and tests on particle kinematics programs ATHOS,<sup>27</sup> H4,<sup>28</sup> H5,

20. Described in Physics Division Semi-annual Report, UCRL-11132, Nov. 1963, p. 71.

21. For a complete description of FOG-CLOUDY-FAIR, see UCRL-1340, CLOUDY-FAIR Data Processing System Reference Manual, by Howard White et al. 1960 through 1964.

22. Described in Physics Division Semiannual Report, UCRL-11466, May 1964, p. 25.

23. Blatt and Weisskopf, Theoretical Nuclear Physics (Wiley, New York, 1950), pp. 392-394.

24. D. C. Jensen and J. C. Cain, An Interim Geomagnetic Field, J. Geophys. Res. **67**, 3568 (1962).

25. I. Harris and W. Priestler, Theoretical Models for Solar Cycle Variations of the Upper Atmosphere, Goddard Space Flight Center Report X-640-62-70, 1962.

26. Described in Physics Division Semiannual Report, UCRL-11466, May 1964, p. 22.

27. M. Horovitz, ATHOS, Alvarez Physics Note No. 394, May 29, 1962.

28. Mark Horovitz, Four-Body Phase Space Program, Alvarez Physics Note No. 395, May 1962.

H6, and SUM<sup>29</sup> were completed. (Mark Horovitz and Tom Tonisson for Alvarez Group)

The program PARTMASS was written to calculate kinematical quantities for the reaction  $1 + 2 \rightarrow 3 + 4$ . (Edna Williams for William M. Layson, Lofgren Group)

A semi-infinite definite error integral was evaluated for various parameter values by a

29. Tom Tonisson, SUM, Alvarez Physics Note No. P-86, May 1964.

program called ERF.<sup>30</sup> (Marilyn Mahan for Rae Stiening, Segrè-Chamberlain Group)

A short FORTRAN IV program, RAE, was written to compute the angular spectrum of  $\mu$ -e decays in flight. The spectrum was needed for correction of the  $K\mu_3$ - $\mu$  polarization experiment. (Edna Williams for Rae Stiening, Segrè-Chamberlain Group)

30. Described in Physics Division Semiannual Report, UCRL-11466, May 1962, p. 25.

### Spark Chambers

#### Moyer Group

The program CENTER<sup>31</sup> was further developed by incorporating options for fixing the probable point of coincidence of the set of non-intersecting tracks on the first track or on the beam line. Additional output was provided to facilitate checking consistency of CENTER with other programs used in the experiment. (Leslie Wilson for Selig Kaplan)

Cheng Experimental program was written for the PDP-5. During the experiment, the program enters an infinite loop, producing a display on the CRT. When a piece of data comes, the machine is interrupted and the data are processed and written on magnetic tape. (Anthony Schaeffer for David Cheng)

#### Lofgren Group

The program MOCA was written in FORTRAN IV on the IBM 7044. MOCA is a Monte Carlo problem with five variants, including two uniform distributions ( $0 \leq X \leq 1$ ,  $0 \leq X \leq 2\pi$ ), one distribution according to the Breit-Wigner form,<sup>23</sup> and two other distributions. (David Leppaluoto for Charles Ankenbrandt)

The program KAPANAL was converted to FORTRAN IV and extended by addition of option for plotting output via CAL-COMP Plotter. (Leslie Wilson for Ching L. Wang)

Two special-purpose PDP-5 programs were written in connection with Leroy Kerth's Bevatron experiment. One program, PLOT, plots arrays of double precision integers on the scope attached to the PDP-5. Another program, FIT, computes a least-squares fit on sets of data points with fixed abscissa values. (William Benson for Leroy Kerth)

31. Described in Physics Division Semiannual Report, UCRL-11466, May 1964, p. 23.

The 1401 program BASIC<sup>32</sup> was completed. The program was written to perform preliminary processing of spark chamber data produced by the SCAMP machines. (Arnold Nirdlinger for Leroy Kerth)

#### Crowe-Haddock Group

The program TRGTRK was written to recognize tracks in the target chambers of the Crowe Bevatron experiment from Vidicon data. The Vidicon data for one event consist of as many as four sparks in each of fourteen gaps in each view, two views for each of three chambers. The method is basically the same as that employed in the program VIDICON<sup>33</sup> written for the Perez-Mendez experiment. However, further difficulties are caused by the presence of multiple tracks, showers, and deflected tracks. (Leslie Wilson for Roy Haddock)

OLD CROW is a PDP-5 program for the Crowe Bevatron experiment. The PDP-5 will be used for on-line data gathering and monitoring of the experiment. Raw data will also be put out on magnetic tape for further analysis by the 7094. (Anthony Schaeffer for Roy Haddock)

Work was begun on a 7094 equipment-monitoring program, EMP, for the Crowe Bevatron experiment. The program will read two sets of tapes which are produced by a PDP-5 used as an on-line data gathering device, and by a target Vidicon. Counters and wire chamber addresses will be logged, events identified, angles between tracks computed, and various spectra plotted. Raw data from relatively rare events will be written on a separate output tape to facilitate later searching for these particular classes of events. (William Benson for Roy Haddock)

32. Described in Physics Division Semiannual Report, UCRL-11466, May 1964, p. 24.

33. Described in Physics Division Semiannual Report, UCRL-11466, May 1964, p. 23.



### Chamberlain Group

A set of DDP programs was begun for the automatic scanning and preliminary analysis of data from the Chamberlain K- $\Sigma$  parity experiment. Basic data consist of 35-mm photographs of the complex of spark chambers surrounding the target.

The programs and their functions are as follows:

A DDP-24 program, SFAT (Search For All Tracks) was begun. It positions the film, and detects and decodes the binary information contained in the neon lights recorded on the film. Tests are performed on this information to determine whether the current frame is to be considered. If so, each of the views of the various chambers is examined. First the fiducials for a particular view are calculated--then all tracks in all gaps in the view are located. This information is stored in an output buffer area. Tests are performed to

insure that the proper numbers of sparks appear in certain chambers. All tests having been successfully passed, the output buffer, containing the coordinates of all the sparks located in the various views, together with the coordinates of the fiducials, is written out in a single record on magnetic tape.

A DDP-24 program, SFAF (Scan For A Fiducial), was written together with the necessary dummy routines to facilitate its debugging. The fiducial marks are L-shaped with a gap at the vertex. There are four possible orientations of the L. Given a rough location for the vertex, SFAF locates the end points of the two sides of the L, constructs straight lines through these end points, and calculates their intersection. The coordinates of the intersection are rounded off and returned to the calling program.

The 7044 program, SHERLOCK, was begun, which will perform kinematic analysis of the data from the tape produced by SFAT.

### Chemistry

Two FORTRAN IV programs were written to aid in the investigation of interactions between extranuclear magnetic or electric fields and the electromagnetic moments of short-lived excited nuclear levels. These interactions are detected by an anisotropic angular correlation between  $\gamma$  rays of a cascading decay at the intermediate nuclear level. The program DELT fits an exponential function and a cosine wave to "time differential" measurements, where the interaction is observed as a periodic modulation of the decay of the intermediate nuclear level; the program INT fits "time-integrated" measurements in order to obtain the magnetic interaction frequency from the anisotropy measured as a function of magnetic field. (Claudette Ruge for Eckart Matthias)

Three general nonlinear least-squares programs, EXPFIT, POLYFIT, and GAUSFT, were written in FORTRAN IV on the IBM 7044-94. The fitting functions are:

(a) EXPFIT: sum of up to 10 exponentials  $A e^{-\lambda x}$ , with A and  $\lambda$  to be determined.

(b) POLYFIT: sum of up to 7 even Legendre polynomials  $A P_I \cos(\theta - \theta_0)$ , with A and  $\theta_0$  to be determined (I even).

(c) GAUSFIT: sum of up to 9 Gaussian functions  $A e^{-1/2[(x-\mu)/\sigma]^2}$ , with A,  $\mu$ , and  $\sigma$  to be determined.

To aid in setting up fission threshold experiments a FORTRAN IV program was written to calculate the theoretical fission threshold values of the bombarding energy, excita-

tion energy, and Coulomb barrier, given a set of targets and various projectiles. The program called THRES tabulates and sorts the results with respect to target or excitation energy. (Claudette Ruge for Stanley Thompson)

A program FUNC was written which evaluated the arc cotangent of a function. (Marilyn Mahan for Rand Watson)

The program AUTOSPECT (a revision of code POLYGNU<sup>34</sup>) was completed and put into production. The program processes a raw data tape which is generated by a tape recorder. The project is to measure large numbers of spectral lines and compute their wavelengths and wave numbers by means of a least-squares fit to a sixth-degree polynomial. The calculations are performed by use of double-precision arithmetic. (Jerry Borges for John Conway)

Program BETABLE<sup>35</sup> was run and revised. A subroutine to compute first derivatives analytically from eigenvalues and eigenvectors obtained from a single matrix inversion was completed. This decreases computing time by a factor between 2 and 4, depending on the number of parameters being varied. A routine

34. Described in Physics Division Semiannual Report, UCRL-11132, Nov. 1962, p. 73.

35. Laboratory Computer Center writeup Z0 E0 Z018 is available from Judith Lawrence, Computer Center Library (Bldg. 50A, Rm. 1148, Ext. 5871).

to compute Taylor series for eigenvalues using first, second, and third derivatives obtained from a single matrix inversion was begun. Copies of the program were sent to Argonne and UCLA.

A program TAPMAK, to prepare input representing ions in a crystal, was begun. (Thomas Clements for John Conway)

A program LAWFIT was written to fit a sum of Lorentzian curves to Mössbauer absorption spectra as normalized by CATFIT. A modified version of VARMINT<sup>36</sup> is used and the resulting fit plotted with the data via the CAL-COMP Plotter. (Leslie Wilson for Marjorie Faltens)

Work was completed on the program DRUM,<sup>37</sup> which tabulates events of a cyclotron experiment. The experiment is concerned with the level structures of a fissioning nucleus at the saddle-point distortion. A CAL-COMP Plot routine was added to display the distribution of events in histogram form. (Noel Brown for Frank Plasil)

A program SCATTER was written to formulate and solve the coupled complex differential equations for scattering from an even nucleus.

The program BRAKET,<sup>38</sup> which computes the transformation bracket function for nuclear shell-model calculations, was modified for speed and output flexibility. (Noel Brown for Norman Glendenning)

The program PRIME was converted to FORTRAN IV. PRIME calculates the parameters describing nuclear alignment as a function of temperature. (Noel Brown for Richard Frankel)

A program NORM was written to compute

theoretical Mössbauer curves and to allow quantitative determination of the electronic relaxation time as evidenced by experimental Mössbauer spectra.

A program LORENTZ was written to facilitate interpretation of complex Mössbauer resonance by computing total absorption patterns which were composites of 18 distinct Lorentz curves.

A program LAMTBL was written to compute energy levels and g values for the Hamiltonian

$$H = E (S_x^2 - S_y^2) + D [S_z^2 - \frac{1}{3} S(S+1)]$$

as a function of  $\lambda \equiv E/D$ . This Hamiltonian is applicable to many Fe compounds. (Edna Williams for H. Hollis Wickman and David Shirley)

The program DIABLO,<sup>39</sup> which provides a method for taking data from a punched paper tape and putting the data on magnetic tape in a form compatible with FORTRAN, as well as writing a CAL-COMP tape for plotting purposes, was modified in several ways. The plotting option was eliminated (since plotting is now being done on-line), the program was converted to FORTRAN IV and MAP, and provision for paper tape parity checking (which was not possible in the original program because the paper tape end-of-record code was out of parity) was added. (Anthony Schaeffer, Donald Zurlinden, and David Leppaluoto for Bernard Harvey)

Work was begun on a general-purpose routine, CCCP, to use the CAL-COMP Plotter on the PDP-5. This routine will scale and plot arrays of double-precision integers, letter characters anywhere on the paper, and draw grid lines. The automatic multiply-divide feature is used, but is not essential. (William Benson for Bernard Harvey)

### Inorganic Chemistry

A program GGRAPH was written for the 7044 and the CAL-COMP Plotter to display the results of a curve-fitting program written by Eric Beals. (Majory Simmons for Daniel Fiat)

The program DELFT was written to perform numerical integration on two sets of

36. Laboratory Computer Center writeups Z0 E0 Z013 and Z0 E0 Z014 are available from Judith Lawrence, Computer Center Library (Bldg. 50A, Rm. 1148, Ext. 5871).

37. Described in Physics Division Semiannual Report, UCRL-11466, May 1964, p. 26.

38. Described in Physics Division Semiannual Report, UCRL-11466, May 1964, p. 26.

tabulated data; the difference between the integrals is printed out and further calculations, including a numerical integration, are performed on the differences. (Marilyn Mahan for William Gardner)

The program HEAT was written to calculate heat capacities from experimental data and fit the temperature-dependent results to any of a number of equation forms. (David Leppaluoto for William Gardner)

39. A writeup on DIABLO is available in the Lawrence Radiation Laboratory Computer Center Library from Judith Lawrence (Bldg. 50A, Rm. 1148, Ext. 5871).

In cryogenic calorimetry, temperature is commonly measured by using the temperature dependence of resistance of a semiconducting device such as a graphite film or doped germanium crystal. These devices are calibrated by measuring their resistances at a number of points on some well-established temperature scale. Once this resistance thermometer is calibrated, it is necessary to devise a scheme for finding the temperature corresponding to a given resistance value. This is usually accomplished by a least-squares fitting, possibly

nonlinear, of the calibration data to an expression which describes the temperature dependence of the resistance. Once a fit is obtained, the fractional residuals are plotted against calculated temperatures for each calibration point and a smooth curve is drawn. This curve then provides a correction for the imperfection of fit at any point. A program EXFIT is being written to perform the necessary calculations and plots. (Edna Williams for William Gardner)

### Biology and Medical Physics

The analysis of experiments on Fe<sup>59</sup> kinetics in humans has been continued. Previously a code RAD,<sup>40</sup> had been written to fit a certain theoretical form to activity measurements in the plasma and to graphically display the measurements taken over liver spleen and sacrum. It was soon realized that it would be preferable to use one theoretical model which could be simultaneously compared with the various kinds of data.

Several models were programmed and the results compared with previously hand-calculated ones. Fairly good correspondence has been found between our model and the one proposed by Dr. Pollycove and Dr. Mortimer in 1961<sup>41</sup> for normal patients. Work is presently being done on extending the model to handle nonnormal patients. At this time the computer code 9B21 originated by the National Institute of Health - Office of Medical Research, is being employed in the model solving.

The nonlinear least-squares fitting program 9B21 was used to fit a compartmental model to selected data cases. Satisfactory fits were obtained; however, the best fitting parameters obtained differed appreciably from values found by a (nonanalogous) hand calculation. Their use in calculating other physiological parameters yields reasonable results.

A mathematical model of blood iron kinetics and erythron development was worked out. The model, called NOONEYMODE, is the first mathematical model to include explicitly the maturative and proliferative processes of the erythron. Used in conjunction with certain radioactivity-monitoring procedures, the

model is expected to yield quantitative information on proliferation and iron uptake of erythrons as well as on both intra- and extra-medullary hemolysis.

The program VARMINT was adapted to fit data from an albumin extracellular-fluid kinetics experiment of Winchell's to a compartmental model designed by him. Approximately 25 cases were analyzed. (Jerry Borges, Grove Nooney, and Mark Horovitz for Harry S. Winchell)

Modifications were made to two 7044 statistical programs, RATIO and RATTEST,<sup>42</sup> which are used to characterize the skeleton of the rat. (Jerry Borges for Patricia Durbin-Heavey)

The program SPOT (which was written by Bonnie Glaser) was modified and debugged. The code measures photographs of bacterial colonies. (Jerry Borges for John Lyman)

The 7044 code, POLEFIT, was written and debugged. The program does a least-squares fit to a power series of the form

$$Y = \sum_i A_i X^i, \quad Y = \sum_i A_i \sin^i X, \quad \text{or} \\ Y = \sum_i A_i \cos^i X,$$

and produces a CAL-COMP plot of the results. (Jerry Borges for Tom Tenforde and Howard C. Mel)

The program ASTROS<sup>43</sup> was completed and was used to make depth-dose calculations for a sphere in isotropic radiation of protons. The calculation involved the evaluation of triple integrals. The last step in the program was a CAL-plot routine called PLOTP to display

40. Described in Physics Division Semiannual Report, UCRL-11466, May 1964, p. 27.

41. M. Pollycove and R. Mortimer, The Quantitative Determination of Iron Kinetics and Hemoglobin Synthesis in Human Subject, J. Clin. Invest. 40, 753-782 (1961).

42. Described in Physics Division Semiannual Report, UCRL-10572, Nov. 1962, p. 74.

43. Described in Physics Division Semiannual Report, UCRL-11132, Nov. 1963, p. 74.

some of the results. (David Leppaluoto and Anthony Schaeffer for Palmer Steward)

Revisions were made to expand a 7094 program, TAXO, and free it of storage limitations. TAXO was written to evaluate the information

content of biological classifications.<sup>44</sup> (Marjory Simmons for Aldo Rescigno)

44. Described in Physics Division Semiannual Report, UCRL-11466, May 1964, p. 27.

### Health Physics

Given tabulated values of an analytic expression for an integrand, the program COST maximizes the function and plots out curves to give additional information. (Marilyn Mahan for Dong H. Nguyen)

The FLUX program<sup>45</sup> computes neutron energy spectra from measured activities of samples of various elements exposed to this neutron flux. Revision of this program is in progress. Changes are aimed at improving the accuracy of the calculation and removing the possibility of negative flux values in the computed spectra.

The program FLUX has been rewritten in three parts, FLUXS, FLUXP, and FLUXC to solve a system of integral equations. The three programs yield the solution as a step function, as a linear interpolation between N points, and as an expansion in terms of the kernel functions. These solution types have been used in conjunction with VARMINI to restrict the solution to positive values. (William Dempster, Grove Nooney, Jerry Borges, and Mark Horovitz for Alan Smith and Arthur Kohler)

45. John Clayton Ringle, A Technique for Measuring Neutron Spectra ..., UCRL-10732, Oct. 11, 1963.

A subroutine ORNORM was written to produce orthonormal functions from any linearly independent set. (William Dempster for Arthur Kohler)

A program was written called EARTHSHLD. Samples of low-background material are collected and analyzed for radioactivity. EARTHSHLD computes total counting rates in counts per minute per gram, and the individual contributions in counts per minute of U<sup>238</sup>, Th<sup>232</sup>, and K<sup>40</sup> to the total. An analysis is done on errors arising from the statistical nature of the data.<sup>46</sup> (Jerry Borges for Alan Smith)

Additions to several auxiliary Health Physics computer programs were also made. (William Dempster, Grove Nooney, Jerry Borges, and Mark Horovitz for Alan Smith and Arthur Kohler)

A method was formulated to numerically solve a Volterra integral equation of the first kind, where the inhomogeneous term is given as a set of measured data points. The integral equation arises in the field of radiation dosimetry. (Paul Concus)

46. H. A. Wollenberg and A. R. Smith, Earth Materials for Low-Background Radiation Shielding, UCRL-9970, May 24, 1962.

### Electronics Engineering

Modifications were made to CERTFY<sup>47</sup> and its associated programs. These modifications were necessary due to changes in the format of data recorded by the "Rapid Mapper."<sup>48</sup> Improvements were also made in the error-analysis technique of CERTFY.

CERTFY was converted to FORTRAN IV. During conversion much of the program was rewritten for increased efficiency.

47. Described in Physics Division Semiannual Report, UCRL-11132, Nov. 1963, p. 45.

48. Peter Watson, Brief Description of Operations and Performance Specifications of LRL Rapid Magnet Field Mapping Systems, Engineering Note MT164, August 8, 1963.

A program PLINT was written to compute and plot on the CAL-COMP Plotter the line integrals of magnetic field measurements.

Several programs were written for processing 72-inch bubble chamber magnetic field measurements recorded by the "Rapid Mapper." The programs were necessary because of the uniqueness of the data.

CORTAN was written for converting magnetic field measurements taken in a rectangular coordinate system to field measurements given in polar coordinates.

Work was begun on a program, COFMID, to compute off-midplane magnetic field meas-

urements based on measurements taken in the midplane. (Bert Albrecht for Peter Watson)

The program LARGE<sup>49</sup> was modified in various ways to complete calculations involved in analysis of traveling-wave beam electrodes. (Leslie Wilson for David Large)

The program CMBES was written to calculate the determinant of a 4-by-4 matrix whose elements were combinations of complex Bes-

49. Q. A. Kerns and D. B. Large, Analysis of a Traveling-Wave Beam Electrode, UCRL-11551, July 7, 1964.

sel functions. By finding a zero of the determinant, the program yields an approximate solution for the propagation characteristics of an inhomogeneous coaxial cable. (Marilyn Mahan for David Large)

The program PRSN was written to solve a nonhomogeneous parabolic linear partial differential equation in two independent variables.

The programs PLASMA and FINAL were written to solve a similar differential in three independent variables. (William Dempster for Gary Pearson)

### Metallurgy

The programs CLOSET and DIFFUS were written to assist in the solution of the ternary diffusion problem. CLOSET solves a system of partial differential equations for the non-linear case, while DIFFUS solves a linear special case. (Leslie Wilson for Yasumichi Oishi)

The program FACTOR was written to calcu-

late the modulus of a complex vector, the real and imaginary parts of which are calculated by triple summations of complex exponentials. (David Leppaluoto for Robert Villagrana)

A program ELASMOT to compute elastic module in an inhomogeneous medium was completed. (Thomas Clements for Didericus Hasselman)

### Livermore

The eigenvalues and eigenfunctions of the vibrational states belonging to the ground electronic state of the hydrogen molecular ion were recalculated by use of a potential function calculated by Henk Wind of the Culham Laboratory in England. A FORTRAN II program called HYDRION was used for the computations, which were done for the  $j = 0, 2, 4,$  and  $7$  rotational states. (Victor Brady for John Hiskes)

A contour integral arising in the study of

particle beam stability in the Astron project at Livermore was evaluated. The method used to calculate the integral was based on a combination of classical steepest descent and numerical techniques. (Paul Concus, Edna Williams)

A program CONTURTEST was written to evaluate a contour integral arising in the study of particle beam stability for the Astron project. (Paul Concus and Edna Williams for Andrew Sessler)

### Miscellaneous

A program MAT was written which solves a least-squares problem and allows the user to vary the number of terms and the functions by means of a control card. Development was begun on another general-purpose least-squares program which may involve any set of linearly independent functions. (Marilyn Mahan for Leonard Finegold, Inorganic Materials)

A survey was made of applications of analog-to-digital converters that could be used to facilitate computer processing of analog signals which are now being displayed and proc-

essed in the form of pen recordings. [Mark Horovitz and Tom Taussig (Electronics Engineering) for Inorganic Materials]

A program, A6118, was written to fit a curve to a given set of data by means of Fourier analysis. This utilized the existing subroutine HAS to provide the Fourier analysis. (William Dempster for Duane Spence, Hilac)

A program DELPHIC to compute stresses and strains in an elastic medium involving the inversion of 100-by-100 matrices, was com-

pleted. (Thomas Clements for Jack Tanabe, Mechanical Engineering)

The program LIKELY was used to calculate the likelihood product as a function of two vari-

ables for a series of experimental data. An attempt was made at making a perspective plot of the likelihood function, but was unsuccessful. (Anthony Schaeffer for Ed Platner, University of Washington)

### Salary and Wage

A program SALDIS was designed for a variety of situations involving salary maturity curve plotting. The curves are third-order polynomially fitted and relate salary to age, experience, or years since B. S. degree.

A program SALPLOT was written which uses data from existing Salary and Wage programs to plot salary curves on the CAL-COMP Plotter.

A 7094 program AVGSAL was needed to replace a 650 program which produced third-order polynomially fitted curves relating average salary to age, experience, or years since B. S. degree.

A program CONVRT was written to convert personnel salary cards to a form usable by another Salary and Wage program, SALDIS. (Edna Williams for Craig Zane)

### Budget

MAJIN, the final chain of the Budget program, SKED 92,<sup>50</sup> does a complete analysis of Laboratory costs. Total major instrument costs, as well as their program distributions,

50. Described in Physics Division Semiannual Report, UCRL-11132, Nov. 1963, p. 76.

are printed for Berkeley physics, Berkeley chemistry, and Livermore machines. A summary of Laboratory costs for the fiscal year is made, listing costs of major programs and other operational, indirect, and maintenance costs. (Ardith Kenney for George Pappas)

### Mathematics and Computing

#### General-Purpose Programs

Work was completed on a report entitled "Capillary Stability in an Inverted Rectangular Channel for Free Surfaces with Curvature of Changing Sign" (UCRL-11515), and it was accepted for publication in the AIAA Journal to appear later this year. (Paul Concus)

A consultant service was established for the purpose of giving programming assistance to computer users.

Work was continued on the evaluation, testing, and debugging of library utility programs and on the preparation of new utility programs.

A complete investigation of the theoretical method of the least-squares fitting program, VARMINT,<sup>51</sup> was carried out. Minor modifications in the method were tried. Major modifications of input and output were incorporated to ease its use. (Eric Beals)

51. William C. Davidon, Variable Metric Method for Minimization, Argonne National Laboratory Report ANL-5990-Rev 1, Nov. 1959.

A program RANGAN was written to generate floating-point numbers uniformly distributed in the interval (0, 1). (Carl Quong)

Routines called GAMMA, which calculate the gamma function and Legendre functions, were converted to FORTRAN IV to take advantage of the built-in complex arithmetic.

The following routines were converted from FAP to MAP: C3-Nu-BCS3, which calculates Bessel functions of real or imaginary arguments or order or both; PSI, which evaluates the derivative of the natural logarithm of the gamma function.

An arithmetic subroutine, LNGAM, to compute the natural logarithm of the gamma function, was written in FORTRAN IV.

The 7090 version of OPTIK<sup>52</sup> was corrected in the subroutine QUADU for off-momentum beams. (Marilyn Mahan)

52. Thomas J. Devlin, OPTIK, an IBM 709 Computer Program for the Optics of High-Energy Particle Beams, UCRL-9727, Sept. 1961.

Programs were begun to find Bessel functions  $J_0$ ,  $J_1$ ,  $Y_0$ ,  $Y_1$  for complex arguments. (William Dempster)

Two programs--LAGINT and LAGRNG--were written to do Lagrangian interpolation of order  $M$  ( $1 \leq M \leq 10$ ) in a user-supplied table. One program is self-sufficient, while the other is a subroutine. (James Eusebio)

A multiple integration subroutine called MULSMP was written. Up to a quintuple integral with variable limits can be calculated by use of Simpson's Rule. The recursion formulas used are the same as those used in subroutine SIMPS.

The program LALS,<sup>53</sup> for fitting data to some arbitrary function, was rewritten in FORTRAN IV. In order to use this set of subroutines the user need only supply a routine for reading the data and specifying necessary parameter values, and a routine which evaluates the fitting function and the derivative of the function with respect to the fitting parameters. (Claudette Rugge)

A set of two programs--AUDIT1 and AUDIT2--was begun for the purpose of recording the amount of time used by each problem of each account number for all LRL groups on all LRL computers, as well as jobs run on campus or elsewhere. AUDIT1 is a pre-processor program which accepts data from time cards from the computer. The various types of error that can occur on these time cards are corrected and the data are ordered according to time; account number and problem name are written on a tape, which is then used as input tape for AUDIT2, a report-generating program. Because of the necessity of reading and writing very long records, it is necessary to include three machine-language subroutines. AUDIT2, the report-generating program, also can give costs charged to each account if desired. (Krehe Ritter)

A series of articles entitled "Field Guide to Computers, Their Habits and Habitats" was published in The Magnet from February through November 1964. This series of articles has been published in combined form as UCRL-11753. Copies are available from Technical Information. (James A. Baker)

### Systems Programming

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

53. R. H. Moore and R. K. Ziegler, The Solution of the General Least Squares Problem with Special Reference to High-Speed Computers, Los Alamos Scientific Laboratory Report LA-2367, Oct. 15, 1959.

### 1. FORTRAN II and IBSYS Monitor Systems (7094)

a. Maintenance and modifications--changes sent to us by IBM--were inserted into the systems where applicable. Since the IBSYS system has been frozen at Version 8, few IBM corrections have been added to IBSYS. (Robert Belshe)

b. System changes were made to allow the running of the FORTRAN II and IBSYS systems on the 7094-B computer. Included are the placing of the system on the 1301 disk file, modification of all clock routines to use the Chronolog clock on the 7094-B, and the writing of CRT routines, CROP and SLOP, which produce plotting information on tape for subsequent plotting on the 7094-A CRT. (Robert Belshe and William Benson)

c. Print and punch output were put on a single output tape. This system modification frees a tape unit for other use. (Robert Belshe)

d. Several IBSYS changes were made; the "variable tape number" subroutine was modified to allow more flexibility; an input-output option was added to allow the computer operator to set tape unit density manually; input-output unit specification subroutines were made compatible with other IBSYS systems in use at the Laboratory. (Robert Belshe and William Benson)

e. Several subroutines were placed on the IBSYS subroutine library which duplicated functions available in the 7044 IBSYS library, thus increasing IBSYS and FORTRAN IV machine independence somewhat. (Robert Belshe and Dave Stevens)

### 2. Diprogramming System Checkout on the 7094-A Computer

a. Final checkout was continued to detect and remove programming errors in the system. Many of the errors found were due to undocumented peculiarities present in the IBSYS system which conflicted with some of the revisions made when the diprogramming system was produced.

b. Modifications to the diprogramming system were necessary when the 7094-A computer was converted to model II. Considerable difficulty was encountered because of a lack of documentation regarding machine behavior on our computer with its attached extra equipment. In addition, several errors in the logical design of model II were encountered, and corrections were made through the combined efforts of the systems programming personnel and the IBM Customer Engineers.

c. Efforts were continued toward making the diprogramming system consistent with the other 7094 programming systems in use. The areas involved were mainly tape usage and CRT usage.

d. The system was modified so that all print and punch output are placed on a single tape. This frees a tape drive for each of the

two concurrently running jobs.

e. An extensive series of timing tests was begun to compare the diprogramming system with standard IBSYS (James Eusebio); complete documentation of the diprogramming system was begun; a study was begun to determine the optimum usage of tape units and disk areas; the writing of an improved version of the Scheduler section of the resident part of the system was begun; and the building of an interrupt generator (Robert Belshe) to be incorporated into the channel H clock was begun. [Myron Myers, William Benson, Gayle Wampler (IBM), Doneley Watson (IBM), and Douglas Brainard]

### 3. 7044 IBSYS Monitor System -- Maintenance and Modification

a. Changes and corrections sent to us by IBM were incorporated into the 7044 IBSYS system. In addition, several system errors were discovered and corrected by Laboratory personnel.

b. The system was modified to allow the simultaneous printing out of one job's output on the 1403 printer while the next job in line was being executed. This technique, which is called SPOOLing (Simultaneous Peripheral Operations On-Line), relieves much of the pressure on the peripheral printer operation and decreases turn-around time, while penalizing the 7044 operation by at most 10%. (Dave Stevens)

### 4. Miscellaneous Activities

a. Two DDP-24 routines, CCPL and TVPL, were written to simulate the plotting of CAL-COMP and CRT tapes on the DDP-24 cathode-ray oscilloscope. In this way, one can scan a CRT tape for useful information without having to actually record all the information on CRT film or on the CAL-COMP Plotter. (William Benson)

b. Two weeks of demonstrations were held, illustrating the IBM experimental Remote Computing System, in which remote keyboards are connected by phone lines to a central computer, in this case a 7090 in New York. The system allows the user to type FORTRAN statements on the keyboard, and to obtain error messages and printed output within a few seconds. (Dave Stevens)

c. A series of programs was run on the CDC 6600 installed at the Livermore Laboratory, to evaluate the basic computing ability of the 6600 with regard to the needs of this Laboratory. Programs run consisted of FORTRAN test programs and a hand-coded machine-language program. (Douglas Brainard)

d. Preliminary plans were made for the upgrading of the 7094 IBSYS systems in use at this Laboratory from the present Version 8 to the soon-to-be-released Version 13. Benefits to be obtained would be the use of the new and

somewhat faster FORTRAN compiler in Version 13, use of a new debugging feature, and the ability to use the current IBM instruction manuals. Since all 7094 IBSYS systems should be at the same modification level, upgrading IBSYS to Version 13 involves system programming modifications to all subroutine libraries and all time-accounting routines, and a complete revision of the entire diprogramming system. (Douglas Brainard)

### 5. 1401 System Programming

The MONITOR TAPE-TO-CARD Program was written for the IBM 1401-1460. This program punches cards from the 7094 combined print-punch tape.

All versions of the MONITOR PRINT Program (MPP, MPP+PLOT, Dual MPP, and 7040 MPP) were revised to ignore binary (punch) records and to handle skew or bit-packed records.

The 1401 Dual MONITOR PRINT Program was modified to run on the 1460. (1460 Dual MPP)

SOPAT II (a 1401 program assembler) was modified to run from our system tape (as opposed to cards or its own system tape), has had several of its bugs removed, and has been improved somewhat. Much of this was done by David Devlin (Stores).

Several other 1401-1460 programs were modified or corrected, including the 7044-support programs as new versions of 7044 IBSYS were released. (Walter Hutchinson)

### 6. PDP-5 Systems Programming

The program PDPTI, a PDP-5 disassembler program, was written. PDPTI will read a paper tape in either RIM or BINARY (not PARITY-BINARY) format on the PDP-5 Keyboard-reader Model 33 ASR. The contents of tape are then interpreted and typed in both numeric and assembly forms. (David Leppaluoto)

A PDP-5 Assembler, ASSM, which runs under IBSYS and is primarily in FORTRAN IV, was written. The program is currently running on both the 7094 and 7044. (Anthony Schaeffer)

A DEBUG system for the PDP-5 was written. The system contains options for dumping, punching, inserting words into memory, etc., all controlled via the typewriter. (Anthony Schaeffer and Donald Zurlinden)

A course on programming the PDP-5 was given. The instruction was given in three sessions. (Anthony Schaeffer)



## 7. DDP-24 Systems Programming

A new loader, called LOAD, was written to process magnetic and paper tape output from DAP and FORTRAN. The new loader gives the capability to load library routines from tape with cross references such that a

called program is loaded only once.

A character-plotting program, CPLT, was written which will display, on the DEC 30 CRT, characters as they are typed on the on-line typewriter, or the contents of memory. (Robert Belshe)

### Computer Operations

Engineering was accomplished on the following DDP-24 items:

- (a) Installation of the DEC Model 30 cathode-ray tube.
- (b) Installation of hardware to provide read-back of the DMA range register.
- (c) Modification to correct operation of interrupt logic.
- (d) Adjustment and modification to tape units to reduce tape errors.  
(Robert Belshe)

A study of tape-transmission problems was made. The LRL Tape Test Program was completed and sent to IBM for distribution. (Paul Rhodes and Walter Hutchinson)

The 7094-A computer was converted to model II in late August. In July, a second 7094 computer (7094-B) was installed. In October, a 1301 disk file was installed on this second machine. As a result of the added computing capacity, the open time at the end of this reporting period amounted to a total of approximately one full shift.

Two 1460's with two 1000-line-a-minute printers on each machine were installed in October. One of these 1460's also has a CALCOMP Plotter attached.

The 7044 computer was converted in August to provide a 2-microsecond machine cycle time. (Paul Rhodes and Marvin Atchley)

PHYSICS RESEARCH

Edward J. Lofgren in charge

## PRODUCTION OF NUCLEON ISOBARS BY 7.1-BeV/c PROTONS

Charles M. Ankenbrandt, Allan R. Clyde, Bruce Cork, Denis Keefe,  
Leroy T. Kerth, William M. Layson,<sup>1</sup> and W. A. Wenzel

We have measured the missing-mass spectrum of nucleon isobars produced in the reaction  $p + p \rightarrow N^* + p$  by 7.1-GeV/c protons incident on a liquid hydrogen target. Scintillation counters detected the recoil protons after momentum analysis. Cross sections were obtained for production of isobars of mass 1238, 1512, and 1688 MeV at momentum transfers of 0.09, 0.15, 0.24, 0.33, and about 5 (GeV)<sup>2</sup>. At low momentum transfers, the spectrum has additional structure at a mass of about 1430 MeV. The  $T = 1/2$  isobar production cross sections at  $|t| = 5$  (GeV)<sup>2</sup> are comparable with the elastic scattering cross section.

1. Presently at Pan American World Airways, Guided Missile Range Division, Patrick Air Force Base, Florida.

The results of this experiment have been submitted to *Nuovo Cimento*.<sup>2</sup>

This experiment has been extended to look for higher-mass isobars, for dibaryon resonances, diboson resonances, and strange-particle production. Protons in the external beam will be incident on a liquid hydrogen or deuterium target. Scattered particles will be detected with a single-channel spectrometer that will be variable in angle from 8° to 70° and up to 7.0 BeV/c. The experiment is scheduled to start at the Bevatron, December 1964.

2. C. M. Ankenbrandt, A. R. Clyde, Bruce Cork, D. Keefe, L. T. Kerth, W. M. Layson, and W. A. Wenzel, Production of Nucleon Isobars by 7 BeV/c Protons, UCRL-11423, July 1964.

## PROTON-PROTON ELASTIC SCATTERING

Allan R. Clyde, Bruce Cork, Denis Keefe, Leroy T. Kerth,  
William M. Layson,<sup>1</sup> and W. A. Wenzel

Differential cross sections for elastic proton-proton scattering have been measured for incident momenta of 3, 5, and 7 GeV/c. The protons scattered backwards in the c.m. system are detected with scintillation counters following analysis with a magnetic spectrometer. Polyethylene and carbon targets were used for momenta of scattered particles between 500 and 4000 MeV/c, and a gaseous hydrogen target was used for scattered momenta below 600 MeV/c. With a few exceptions, the statistical errors are smaller than 1% for the lower momentum transfers, and increase to 5% for 90° scattering in the center-of-mass system. The cross sections at high momentum

transfer are nearly independent of momentum transfer but depend upon incident energy, a result consistent with experiments at higher energy.

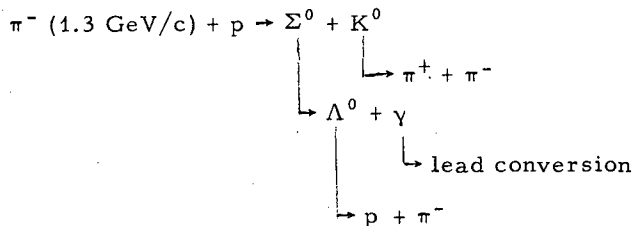
A paper on this subject was presented at the 1964 Dubna Meeting.<sup>3</sup> Final corrections to the cross-section measurements are nearly completed.

3. A. R. Clyde, Bruce Cork, D. Keefe, L. T. Kerth, W. M. Layson, and W. A. Wenzel, Proton-Proton Elastic Scattering, UCRL-11441, July 1964.

$\Sigma$ - $\Lambda$  RELATIVE PARITY

Bruce Cork, Richard L. Crollius, Denis Keefe, Leroy T. Kerth,  
William M. Layson,<sup>1</sup> and W. A. Wenzel

A measurement in spark chambers of  $\Sigma^0$  polarization in the reaction



is nearing completion. Approximately 400 events have been found, all of which show the gamma-ray conversion electrons as well as

the four final heavier particles.

A search will be started soon for events which are like the above except for a Dalitz-pair decay of the  $\Sigma^0$  (that is,  $\Sigma^0 \rightarrow \Lambda^0 + e^+ + e^-$ ). The preliminary search for these events has been completed with the above polarization experiment. If one has polarized  $\Sigma^0$ 's in this last reaction, the  $\Sigma$ - $\Lambda$  relative parity can be found by correlating the  $\Lambda^0$  polarization with the orientation of the Dalitz-pair plane; however, the number of Dalitz decay events will probably be insufficient to do a relative parity determination even if the  $\Sigma^0$ 's have significant polarization.

## SCANNING AND MEASURING EQUIPMENT

Denis Keefe, Leroy T. Kerth, and W. A. Wenzel

The new SCAMP scanning measuring projectors for spark chamber film are now debugged and are scheduled about 3/4 of full capacity. They are currently being used by three groups at LRL. The University of Washington has completed the scanning of almost 300 000 pictures by use of the machines.

Work on SASS, the automatic scanning system for spark chamber photographs, has

proceeded. The mechanical work is about 90% complete and the electronic fabrication is 60% complete. Testing and evaluation of the CRT's is under way. The device should be ready to connect to the computer in January 1965. Most of the programming for the initial checkout phase has been done, and some of the programming necessary for use on the experiment of the Chamberlain Group is in hand.

 $K^-$ -PROTON INTERACTION

Edgar F. Beall,<sup>4</sup> William R. Holley, Denis Keefe, Leroy T. Kerth,  
John J. Thresher,<sup>5</sup> Ching Lin Wang, and W. A. Wenzel

The analysis of the elastic scattering and the recoil proton polarizations of the data collected on  $K^-$ -p interactions between 700 and 1400 MeV/c is almost completed.

Elastic  $K^-$ -proton angular distributions have been obtained at 16 momenta ranging from 700 to 1400 MeV/c. The differential cross sections have been corrected for scanning and measuring

efficiency, decay in flight, beam contamination, loss of scattered particles due to second interaction and absorption in the target and spark chambers, and geometrical efficiency for detecting elastic events. The angular distributions are being fitted to Legendre polynomial power series, and an extensive phase-shift analysis is contemplated.

Angular distributions of polarizations based on 477 proton-carbon scattering events were obtained at five incident beam momenta. Both single energy and energy-dependent phase-shift analysis are under way, utilizing elastic differential cross sections and polarizations.

4. Presently at the University of Maryland, Department of Physics, College Park, Md.
5. Work performed while on leave from the Rutherford High Energy Laboratory, Chilton, England.

$\pi$ - $\pi$  INTERACTION

Denis Keefe, Leroy T. Kerth, Carl M. Noble, John J. Thresher,<sup>5</sup>  
W. A. Wenzel, and Theodore F. Zipf<sup>6</sup>

The 4-BeV/c and 3-BeV/c data have been measured, yielding 1500  $\pi^+\pi^-n$ 's each at low momentum transfer. The  $\pi$ - $\pi$  invariant mass

spectrum shows two enhancements at 715 and 800 MeV.

6. Presently at Brookhaven National Laboratory, Upton, Long Island, New York.

The 7094 programs for angular distributions, phase-space corrections, weighting factors, and kinematical constraining are in the final debugging stage at this time.

## PAPERS ISSUED

Edward J. Lofgren, Cyclotron (UCRL-11554, July 1964). Paper has been submitted to The Encyclopedia of Physics, (Reinhold Publishing Corporation, New York).

Kenneth C. Crebbin, A New Method of Observing the Phase Oscillations in a Synchrotron (UCRL-11610, Aug. 1964), submitted to Rev. Sci. Instr.

PHYSICS RESEARCH

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

EXPERIMENT ON THE CHARGE-EXCHANGE INTERACTIONS IN  
ELASTIC PION-PROTON SCATTERING

Charles Chiu

As was explained in the preceding Semiannual Report, the experiment on the determination of the angular distributions of  $\pi^- p \rightarrow \pi^0 n$  is one of a series of experiments on pion-nucleon elastic scattering on which the Moyer-Helmholz Group has been engaged in order to study the nature of the resonancelike behavior in the region of the incident pion kinetic energy (lab) from 500 to 1500 MeV. The Bevatron run for this experiment was finished at the end of October 1963.

About a half million pictures were taken during the run. Preliminary results were first reported at the American Physical Society meeting in Pasadena last December, and later at the Washington, D. C., meetings last May. At the end of the preceding semiannual period about 7% of the total film had been scanned and analyzed.

During the period of this report, the scanning technique has been further improved. The output rate in the last couple of months has more than doubled that in May. With the gradual improvement in scanning technique, more than 40% of the film has been scanned in this period. It is estimated that, at this rate, all scanning should be completed in about 6 months.

Most of the available data through last July were summarized and reported at the Dubna meetings in August 1964.<sup>1</sup> Eight angular distributions for charge exchange were included, ranging from 533 to 1311 MeV. Further corrections, such as sophisticated consideration of background subtractions and the estimation of the effect of the nonuniformity of the chamber assembly, are still to be considered. Some of these distributions have significant improvements in statistics over those reported

previously. The data of the three highest energies were newly added. These angular distributions have been expanded in the conventional cosine polynomial expansions

$$d\sigma/d\Omega^* = \sum_i a_i \cos^i \theta_{\pi^0}^*$$

The improved data are consistent with those in our earlier reports mentioned above. At 900 MeV, the coefficients again suggest a dominant contribution due to the interferences of the  $F_{5/2}$  and  $D_{5/2}$  waves, both in the pure  $T = 1/2$  state. At 600 MeV the situation is quite complicated and deserves a few words of explanation.

In the early work on the angular distributions of  $\pi^- p \rightarrow \pi^- p$ , the coefficient  $a_3$  between the region of the first and second resonances strongly suggests an interference behavior between the wave which resonates at the first resonance and that at the second resonance. With this in mind one interpreted the coefficient  $a_3$  as being dominated by a single interference term of  $P_{3/2, 3/2}$  and  $D_{1/2, 3/2}$ .<sup>2</sup> Since the interference between  $P_{3/2, 3/2}$  and  $P_{1/2, 3/2}$  cannot occur in this coefficient, the assignment of  $D_{1/2, 3/2}$  as a resonant state is favored. At 600 MeV, if  $a_3$  for  $\pi^- p \rightarrow \pi^- p$  is indeed dominated by the interference term between  $T = 3/2$  and  $T = 1/2$  amplitudes, it is well known that the sign of the coefficient  $a_3$  for charge exchange should be opposite that for  $\pi^- p$  elastic scattering and the behavior of both  $a_3$ 's should otherwise be the same. Thus the role of charge-exchange data here is clear. It offers a severe test to the earlier interpretation mentioned above. It turns out that when one combines our charge-exchange data with those of Lind at lower energies<sup>3</sup> one will notice that the  $a_3$  coefficient for charge-exchange indeed has opposite sign to that for  $\pi^- p$  elastic

1. B. J. Moyer, Pion-Nucleon Scattering in the  $T = 1/2$  State as Deduced from Recent Experiments, UCRL-11577, July 1964; Vincent Z. Peterson, Robert J. Cence, and Victor J. Stenger, Charles B. Chiu, Richard D. Eandi, Robert W. Kenney, Burton J. Moyer, John A. Poirier, and W. Bruce Richards, Neutral Final States in  $\pi^- p$  Interactions from 500 to 1300 MeV, UCRL-11576, July 1964.

2. B. J. Moyer, Rev. Mod. Phys. **33**, 3, 373 (July 1961).

3. Don Leslie Lind, Differential Distribution of Charge-Exchange and Inelastic Neutrons in  $\pi^- p$  Interactions at 313 and 371 MeV (Ph. D. Thesis), UCRL-11435, July 1, 1964.

scattering. Thus our data are consistent with the earlier speculation. On the other hand, the consistency of the two does not really guarantee the uniqueness of the earlier explanation, because the wave amplitudes in the energy region are quite complex, although the earlier explanation is very plausible. In order to further understand quantitatively the behavior of these complex wave amplitudes in this region, one engages in the detailed phase-shift-analysis work. Our data have been incorporated into their programs by Cence at the University of Hawaii, Roper at Livermore, and Lovelace in England. The additional constraints which charge-exchange data impose on different phase-shift solutions can readily be seen when one compares the different angular distribution predictions for charge exchange from the dif-

ferent sets of phase-shift solutions. At the region around 600 MeV the common features of these solutions are a large  $S_{11}$  wave near the threshold of  $\eta^0$  production and the large imaginary parts for both  $P_{1/2, 1/2}$  and  $D_{1/2, 3/2}$  waves.

The availability now of differential measurements of the three types of scattering--namely,  $\pi^-p \rightarrow \pi^-p$ ,  $\pi^-p \rightarrow \pi^-n$ , and  $\pi^+p \rightarrow \pi^+p$ --makes possible the calculation of the scattering in the pure  $T = 1/2$  state as a function of energy through the resonance region. This pure  $T = 1/2$  scattering shows clearly the onset of a strong  $S_{11}$  amplitude associated with the  $\eta^0$  threshold, and the prominence of the  $P_{11}$  amplitude in the region between 300 and 700 MeV.

## STUDY OF $\eta^0$ PRODUCTION IN THE $\pi^-p$ INTERACTION

W. Bruce Richards

The analysis of the events in the charge-exchange film due to  $\pi^-p \rightarrow \eta^0 n \rightarrow 2\gamma n$  is also continuing. Candidates for identification as  $\eta^0$  are chosen by taking all two-shower events where the center-of-mass opening angle between the two photons lies in the appropriate region of large angles. A fairly complete picture of the total cross section for  $\eta^0$  production in pion-nucleon interactions has been obtained from threshold to 1300 MeV kinetic energy of the incident pion, although we will have much better statistics when the data are completely analyzed. The results for the total cross section as they now stand were presented by Peterson at Dubna.<sup>4</sup> The cross section is characterized by a rapid rise from threshold at 560 MeV to a maximum at 2.5 mb around 650 MeV, and then a decrease again to 0.9 mb at 1300 MeV, highest energy of the experiment.

The angular distributions of the  $\eta^0$  are more difficult to establish, for two reasons. First, in many cases, the number of events in the  $\eta^0$  peak of an opening angle plot is not very much larger than the number of background events under the peak. If, then, the opening angle is the only criterion used to select  $\eta^0$  events for an angular distribution, the background events also in the same opening angle region will be included in the angular distribution, and it may be appreciably distorted by them. A more sophisticated selection in-

volving some determination of the energy of the decaying particle from the showers observed is required.

The second problem arises in the solution of the kinematical equations. In combination with knowledge of the masses of the particles and the incident pion energy, observation of the angular positions of the two showers gives enough information to calculate the direction of the decaying meson, except for determining which sign, + or -, to take at one point in the calculation. In almost all cases, for small opening angles, one choice of sign implies that one of the showers has more lab energy, while the other choice gives the other shower more of the energy. Hence, simply noting which shower is longer in the chambers is enough to determine the proper solution. However, in the analysis of the  $\eta^0$ 's, where the opening angles are much larger, the transformation from the center-of-mass to the laboratory system is often such that either choice of sign gives the same shower more of the energy, even though in different proportions. Then, simple observation of which shower is longer is not enough.

In order to reduce both difficulties, therefore, it becomes necessary to try to determine more carefully the relation between the length of a shower and the energy of the photon which initiated it, and this problem is being studied at this time. The study is complicated by the inefficiencies in the spark chambers.

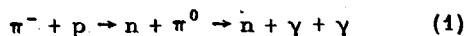
A paper describing this experiment is now in preparation, and will be submitted to Physics Review Letters.

4. Vincent Z. Peterson, Robert J. Cence, and Victor J. Stenger, Charles B. Chiu, Richard D. Eandi, Robert W. Kenney, Burton J. Moyer, John A. Poirier, and W. Bruce Richards, Neutral Final States in  $\pi^-p$  Interactions from 500 to 1300 MeV, UCRL-11576, July 1964.

## CHARGE-EXCHANGE AND RADIATIVE CAPTURE OF NEGATIVE PIONS IN HYDROGEN

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

With a large total-absorption scintillation counter<sup>5</sup> we have detected and measured the energy of photons resulting from the reactions



and



at an incident pion energy of 54 MeV. For (1) we write

$$d\sigma/d\Omega(\theta_{c.m.}) = \sum_{l=0}^2 A_l P_l(\cos \theta_{c.m.})$$

5. William C. Bowman, Jim B. Carroll and John A. Poirier, Rev. Sci. Inst. 33, 741 (1962).

We obtain  $A_0 = (0.71 \pm 0.04)$  mb/sr and  $A_2 = (0.53 \pm 0.09)$  mb/sr.  $A_1$  is not determined. For (2) we obtain

$$d\sigma/d\Omega(\theta_{c.m.} = 90 \text{ deg}) = (50.5 \pm 6.5) \mu\text{b/sr.}$$

Using detailed balance to calculate the isotropic term in the reaction ( $\gamma + n \rightarrow \pi^- + p$ ), we obtain  $a_0 = (14.8 \pm 1.9) \mu\text{b/sr}$  at  $P_{\gamma} = 170$  MeV/c. This value agrees reasonably well with the calculations of Hamilton and Woolcock<sup>6</sup> based on the theory of CGLN.<sup>7</sup>

6. J. Hamilton and W. S. Woolcock, Phys. Rev. 118, 291 (1960).

7. G. F. Chew, M. L. Goldberger, F. E. Low, and Y. Nambu, Phys. Rev. 106, 1345 (1957).

 $\pi^-$ -p ELASTIC POLARIZATION EXPERIMENT AT 184-INCH CYCLOTRON

Dale F. Dickinson, Jerome A. Helland, and Victor Perez-Mendez

The experiment was described in the preceding Physics Division Semiannual Report. The data have been analyzed and the experiment is now being written up.

Polarization values for various values of  $\theta_{\pi}^*$  are given in the following table.

$\theta_{\pi}^*$	P
88.5	-0.42 ± 0.3
98.6	-0.23 ± 0.11
108.4	-0.03 ± 0.1
116.7	0.45 ± 0.11
125.0	0.58 ± 0.15
134.5	0.54 ± 0.16

INELASTIC  $\pi^-$ -p COLLISIONS IN RESONANCE REGION

Douglas Giancoli

The film taken during the most recent Bevatron run on inelastic pion-nucleon reactions is being scanned and computed. The library programs to classify the events and the programs to compute the kinematics, including the momentum distribution of  $\pi^+$  from the  $\pi^+\pi^-N$  final state, have been written and tested. Of the 200,000 events taken during the run, most

have been scanned and measured, and have had the  $\pi^+$  momentum computed. Preliminary  $\pi^+$  distributions and differential cross sections have been obtained. The scanning and measuring of the  $\pi^-$  (a separate set of pictures from the  $\pi^+$ ) has begun and is progressing fairly well. However, the reliability of the film is not yet known.

## n-p ELASTIC POLARIZATION AT ENERGIES FROM 310 MeV TO 700 MeV

David Chang, Kenneth Caproni, Jerome Helland, Burns Macdonald,  
Philip Ogden, William Oliver, and Nahrendar Sehgal

An experiment to measure the n-p elastic scattering polarization parameter for incident proton energies from 310 MeV to 700 MeV is being carried out at the 184-inch cyclotron.

A polarized proton beam was obtained by scattering the cyclotron's external proton beam, degraded to the desired energy, from a carbon target. Two magnets placed ahead of this target control the angle of scattering (from -12 deg to +12 deg) and thus the sign and magnitude of the beam polarization. The polarized scattered beam is momentum-analyzed ( $\Delta p/p \approx 0.03$ ) and focused on a liquid deuterium target. Both the position and direction of the primary beam and of the scattered beam are accurately controlled.

An array of scintillation counters--19 proton counters and 8 neutron counters--is used to obtain events arising from the quasi-free scattering of protons by the neutrons in the deuterium target. All possible combinations of proton-counter and neutron-counter pulses occurring in coincidence can be recorded. Each event, appropriately labeled, is stored in the

memory of a PDP-5 computer. The computer can accumulate groups of up to 1000 events before storing them on a magnetic tape. Data collection is rapid (about 1000 elastic and inelastic n-p events per hour) and, at all energies, is limited only by our ability to monitor the polarized beam accurately.

n-p Elastic polarization data have already been obtained for incident proton energies of 310, 400, 500, 600, and 700 MeV. Preliminary results show good agreement with the asymmetries obtained in previous work by Chamberlain et al. at 310 MeV.<sup>8</sup> Though not originally planned for, data for p-p elastic polarization have also been obtained for the same energies because of the high counting rates possible with this experimental setup (more than 100,000 p-p elastic events per hour). A thorough study of proton-carbon polarization between 310 and 700 MeV will also start soon.

8. O. Chamberlain, E. Segrè, R. D. Tripp, C. Wiegand, and T. Ypsilantis, *Phys. Rev.* **105**, 288 (1957).



PHYSICS RESEARCH

William A. Nierenberg in charge

## ATOMIC BEAM GROUP

Howard A. Shugart

The systematic measurement of various atomic and nuclear properties continues as the primary goal of the atomic beam group. The properties, which are measured on free radioactive atoms in a beam, include nuclear spins, nuclear magnetic dipole and electric quadrupole moments, atomic hyperfine structures, hyperfine-structure anomalies, and electronic angular momenta and g factors. The inherent advantages of beam techniques in obtaining these quantities rest in their conceptual simplicity and sensitivity, and in the ease of interpretation of atomic beam results. From a theoretical viewpoint, the results serve several useful functions. The measurements comprise test information for theories of the nuclear ground state, as well as for ground and low-lying electronic states of free atoms.

The activity of the beam group can be indicated by an enumeration of publications which have appeared during the period of this report.

1. W. Bruce Ewbank and Howard A. Shugart, Hyperfine Structure Separations of Au<sup>191</sup> and Au<sup>193</sup>, Phys. Rev. 135, A358 (1964).

2. David A. Dobson, The Beta Decay Asymmetry and Nuclear Magnetic Moment of Neon-19 (Thesis), UCRL-11169, June 1964.

3. A series of abstracts was presented at the Seventh Brookhaven Conference on Molecular Beams, Uppsala, Sweden, June 1964:

a. D. A. Dobson, F. Calaprice, and E. D. Commins, Beta-Decay Asymmetries of Polarized Nuclei.

b. Vernon J. Ehlers and Howard A. Shugart, Magnetic Field Locking.

c. Vernon J. Ehlers, List of Stable Frequency Sources.

d. Tuncay Incesu and Vernon J. Ehlers, The g<sub>J</sub> Factor of Cs<sup>133</sup>.

e. Howard A. Shugart, Summary of Published Measurements from the Atomic Beam Group at the University of California from April 1962 to May 1964.

f. W. A. Nierenberg and H. A. Shugart, Hyperfine-Structure Computations and the Reduction of Data by Least-Squares Techniques.

g. Paul A. Vanden Bout, Vernon J. Ehlers, and W. A. Nierenberg, Hyperfine Structure of Au<sup>198</sup> and Au<sup>199</sup>.

h. N. A. Williams and E. D. Commins, Radio-frequency Spectrum of the Deuterium Molecular Ion.

4. Joseph Yellin, Richard Marrus, and W. A. Nierenberg, Studies of Optical-Pumping Transients in Rubidium and Cesium Vapors, Bull. Am. Phys. Soc. 9, 563 (1964).

5. Tetsuo Hadeishi, Orilla A. McHarris, and William A. Nierenberg, Radiofrequency of the (2, <sup>2</sup>P<sub>3/2</sub>-3, <sup>2</sup>S<sub>1/2</sub>) State of Neon Produced and Aligned by Electronic Impact, Bull. Am. Phys. Soc. 9, 625 (1964).

PHYSICS RESEARCH

Wilson M. Powell and Robert W. Birge in charge

INTERACTION STUDIES

Analysis of the Decay  $K^+ \rightarrow \pi^0 + \mu^+ + \nu$

George Gidal, George E. Kalmus,  
Wilson M. Powell, Robert T. Pu,  
and Carl L. Sandler

Work is continuing on three aspects of this decay:

1. The determination of the ratio of the form factors ( $\xi$ ) from the  $\mu^+$  energy spectrum.

The analysis of about 2600  $K\mu_3$  events in which the  $\mu^+$  stopped in the bubble chamber is virtually complete.

Results are shortly to be submitted for publication.

2. The determination of  $\xi$  by fitting the Dalitz plot of  $T_\mu$  vs  $T_\pi$ .

A total of 130 events in which the  $\gamma$  rays from the  $\pi^0$  converted and the  $\mu^+$  stopped in the chamber have so far been found. These events were plotted on a Dalitz plot and the population obtained was compared with that predicted for various values of  $\xi$  (modified by the detection efficiency for that event). A best fit of  $\xi$  was obtained. Preliminary results were submitted to the 1964 International Conference on High Energy Physics, Dubna. Work is continuing to increase the statistics.

3. A test of Time-Reversal Invariance.

Under time-reversal invariance there can be no component of  $\mu^+$  polarization perpendicular to the decay plane (in the  $K^+$  center of mass).  $K\mu_3$  events were scanned where the  $\gamma$  rays from the  $\pi^0$  converted and the  $\mu^+$  stopped in the chamber. The  $\mu$  polarization was measured by looking at the  $\mu$ -e decay. It should be noted that the only component of polarization conserved is the one parallel to the magnetic field. So far not enough statistics are available even to show a maximal violation of time-reversal invariance.

1. George Gidal, Wilson M. Powell, Robert T. Pu, Carl Sandler, Ugo Camerini, W. F. Fry, Ronald Hantmann, Robert March, David Murphree, and Sergio Natali, Form Factors in  $K\mu_3$  Decay, UCRL-11547, July 1964.

The work on the longitudinal component of the  $\mu$  polarization reported in the preceding Semiannual Report is now complete and published.<sup>2</sup>

The work reported here has all been done in collaboration with members of the Fry-Camerini group at the University of Wisconsin.

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

George E. Kalmus and Anne Kernan

In the continuing study of  $K^+$  decays we have analyzed 242 events which fit the hypothesis

$$K^+ \rightarrow \pi^0 e^+ \nu$$

$$\rightarrow 2\gamma \rightarrow 2(e^+e^-).$$

The  $K^+$  mesons were stopped in the Berkeley 30-inch heavy liquid chamber, filled with Freon. The kinematics of  $K\pi_3$  decay are over-determined when pair conversion of both  $\gamma$  rays from  $\pi^0$  decay occurs.

The spectra of the decay products are consistent with a pure vector interaction, as predicted by the V-A theory. We find that the energy dependence of the form factor in  $K\pi_3$  decay is

$$f_+ \propto 1 + (0.02^{+0.04}_{-0.03}) \frac{q^2}{M_\pi^2};$$

$q$  is the magnitude of the four-momentum transfer from kaon to pion.

A preliminary report on this work was submitted to the 1964 International Conference on High Energy Physics, Dubna.<sup>3</sup> Additional events are being measured and the analysis of the data continues.

This work is being done in collaboration with Ugo Camerini at the University of Wisconsin.

2. George Gidal, Wilson M. Powell, Robert March, and Sergio Natali, Phys. Rev. Letters 13, 95 (1964).

3. George E. Kalmus, Anne Kernan, Ugo Camerini, and Cyril Henderson, Analysis of the Decay  $K^+ \rightarrow \pi^0 + e^+ + \nu$ , UCRL-11553, July 1964.

sin and with Cyril Henderson at University College, London, England.

The Reaction  $n + n \rightarrow n + p + \pi^-$  at 1.8 BeV/c

Robert W. Birge, Robert P. Ely,  
George Gidal, George E. Kalmus,  
Anne Kernan, and Sedong Kim

We are studying the reaction  $nn \rightarrow np\pi^-$  in the 20-inch Brookhaven deuterium bubble chamber, using a 3.65-BeV/c separated deuteron beam from the AGS. The events are selected from the reactions  $dd \rightarrow ppp\pi^-n$ , in which two protons are spectators. A total of 1100 of these events has been measured. A report on the analysis of 500 events was presented to the 1964 International Conference on High Energy Physics, Dubna.<sup>4</sup>

$\pi^-p$  Interaction at 3.9 BeV/c

Robert W. Birge, Robert P. Ely,  
and Thomas Schumann, with  
Z. G. T. Guiragossian and M. N. Whitehead,  
Stanford University

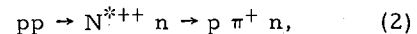
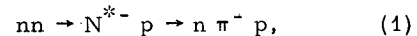
Preliminary results of the study of  $\pi^-p$  interactions at 3.9 BeV/c were presented at the 1964 International Conference of High Energy Physics at Dubna.<sup>5</sup> In particular, reactions giving two visible prongs were constrained, and invariant masses of the  $2\pi$  systems plotted. These showed the usual well-known resonances but with a considerably narrower width for the  $p^0$  than other previous measurements. There also exists an indication of new resonances in both the neutral and charged  $2\pi$  system.

The analysis of four visible-prong data is still under way, along with the analysis of the unconstrained (more than one neutral) events.

Measurement of the  $N^{*-} - N^{*++}$  Mass Difference

George Gidal, Anne Kernan, and Sedong Kim

The unitary symmetry scheme relates the electromagnetic mass splittings within different isotopic multiplets. We are measuring the mass difference  $\Delta m(N^*) = m(N^{*++}) - m(N^{*-})$  for the 1238-MeV nucleon resonance. The  $N^*$  production is observed in the reactions



and  $\Delta m(N^*)$  is determined by comparing the effective mass distributions of  $(n \pi^-)$  and  $(p \pi^+)$  in Reactions (1) and (2). Both reactions are seen in bubble chamber film of d-d interactions at 3.65 BeV/c. The film was taken at the AGS with the Brookhaven 20-inch deuterium bubble chamber. A total of 1000 events of each kind has been measured. Since electromagnetic splittings are commonly less than 10 MeV, the measurement depends critically upon the elimination of all biases in the data. We are presently examining these biases. A preliminary report on this measurement was presented at the 1964 International Conference on High Energy Physics at Dubna.<sup>6</sup>

$K^-p$  Interactions from 825 to 1100 MeV/c

Robert W. Birge, Robert P. Ely,  
James Louie, and Jack Sahouria

Approximately 600 000 picture of  $K^-p$  and  $K^-d$  with incident beam momentum ranging from 825 to 1100 MeV/c have been taken in the 25-inch bubble chamber. The analysis of the deuterium film is reported in the following segment. Approximately 10% of the film has been scanned for  $K^-p$  elastic scatterings. This has resulted in about 10 000 events throughout this energy range which have been measured on the FSD and processed through FOG-CLOUDY-FAIR. Angular distributions for these events are in the process of being completed.

About 20% of the film has been scanned and measured on the FSD for inelastic events involving a V. Analysis of these data are also in progress.

$K^-n$  Interactions at 916 MeV/c

George E. Kalmus, Anne Kernan, and  
Wesley M. Smart

We are investigating the reactions



at a beam momentum of 916 MeV/c. The interactions were produced in the LRL 25-inch chamber filled with deuterium. The range of energies (c. m.) is 1700 to 1800 MeV owing to the Fermi motion of the target neutron. The primary purpose of this experiment is to confirm the existence of the  $Y_1^*$  resonance at

4. Robert Birge, Robert Ely, George Gidal, George Kalmus, Anne Kernan, and Sedong Kim, The Reaction  $n + n \rightarrow n + p + \pi^+$  at 1.9 GeV/c, UCRL-11550, July 1964.

5. Robert W. Birge, Robert P. Ely, Jr., Thomas Schumann, Zaven G. T. Guiragossian, and Marian N. Whitehead,  $\pi^-p$  Interactions at 3.9 GeV/c, UCRL-11556, July 1964.

6. George Gidal, Anne Kernan, and Sedong Kim, Measurement of the  $N^* - N^{*++}$  Mass Difference, UCRL-11543 Rev., July 1964.

1765 MeV, and to determine its quantum numbers.

To date 65% of the film has been scanned, giving a total of 3000 events (1) and (2). Of these events, 25% have been measured.

This work is being done in collaboration with Robert T. Pu, University of California, Riverside.

### Sigma-Hyperon Production

Robert P. Ely and Yu-Li Pan

Sigma hyperons produced with two pions by 1.15-BeV/c  $K^-$  on neutrons in the 30-inch propane bubble chamber were used to study final-state interactions of the particles.

The data indicate the existence of a  $T = 2$  sigma-pion resonance at a mass of  $1415 \pm 16$  MeV. Partial<sup>7</sup> and full<sup>8</sup> results have been reported.

### Sigma-Pion Resonance

Robert Bell, Robert P. Ely, Yu-Li Pan, and Robert T. Pu

Evidence for the existence of a  $T = 2$  sigma-pion resonance has been reported by Pan and Ely.<sup>9</sup> To verify its existence, we are studying the reaction  $K^- + d \rightarrow \Sigma^- \pi^- \pi^+ + p$  with 950-MeV/c  $K^-$  in the 25-inch chamber. Scanning and measuring have been completed. Analysis of the data is in progress.

### Analysis of the $Ke_4^+$ Decay

Powell-Birge Group

Film from the stopping  $K^+$  run in the 30-inch bubble chamber filled with Freon ( $C_3F_8$ ) has been scanned for the decays

$$K^+ \rightarrow \pi^+ \pi^- e^+ \nu [Ke_4(e^+)]$$

$$\rightarrow \pi^+ \pi^+ e^- \bar{\nu} [Ke_4(e^-)].$$

The entire film of 240 000 pictures, with an average of 12 stopped  $K^+$  per picture, has been scanned twice for the above decays. A total of about 800 candidates of the variety  $Ke_4(e^+)$  were picked up, together with about 10 candidates for  $Ke_4(e^-)$ . After measurement and constraining,

7. Yu-Li Pan and Robert P. Ely, Phys. Rev. Letters 13, 277 (1964).

8. Yu-Li Pan, Sigma-Pion Final-State Interactions, UCRL-11568, Aug. 1964.

9. Yu-Li Pan and Robert P. Ely, Phys. Rev. Letters 13, 277 (1964).

the total number of  $Ke_4(e^+)$  accepted was 69 and no examples of  $Ke_4(e^-)$  were left.

The interest in this work is twofold:

Firstly, the ratio of the decay rates for  $Ke_4(e^-)$  to  $Ke_4(e^+)$  can give information on the violation of the  $\Delta Q = \Delta S$  rule for axial vector currents under certain assumptions. The assumptions are that the vector current in  $Ke_4(e^+)$  is negligible, and that the enhancement factor due to the  $\pi\pi$  final-state interaction either is small or can be calculated.

Secondly, the decay rate for  $Ke_4(e^+)$ , the shape of the  $\pi\pi$  invariant-mass spectrum, and the angular correlations in the  $Ke_4(e^+)$  decay give valuable information on the form of the  $\pi\pi$  interactions at low energies in the absence of any other strongly interacting particles in the final state.<sup>10</sup>

A preliminary report on this work was submitted to the 1964 International Conference on High Energy Physics, Dubna.<sup>11</sup>

The final analysis of the results is in progress.

This work is being done in collaboration with the Fry-Camerini group at the University of Wisconsin.

### $K^-$ Interactions in $C_3F_8$ at Approximately 1 BeV/c

Wilson M. Powell and Larry O. Oswald

Approximately 250 000 pictures of  $K^-$  at incident momenta from 900 to 1050 MeV/c were taken in the 30-inch heavy liquid chamber. The purpose of these pictures was to study hyperfragment production. The analysis will be carried out by Professor W. F. Fry's group at the University of Wisconsin.

A special feature of this run consisted of a 45-deg mirror inserted into the chamber itself at one side so that in each view there were both a direct view and a view at right angles to the normal camera axis. This provided right-angle stereo, with which we expect to be able to identify hyperfragments of much shorter range

10. See, for example, E. P. Shabalin, Zh. Eksperim. i Teor. Fiz. 39, 345 (1960), and N. Cabbibo and A. Maksymowics, Angular Correlations in  $Ke_4$  Decays and Determination of Low-Energy  $\pi-\pi$  Phase Shifts, UCRL-11590, Aug. 1964.

11. Robert W. Birge, Robert P. Ely, George Gidal, George E. Kalmus, Anne Kernan, and Wilson M. Powell; U. Camerini, W. F. Fry, J. Gaidos, D. Murphree, and C. T. Murphy, An Analysis of  $Ke_4^+$  Decays, UCRL-11549, June 1964.

than has been possible in the past. The illumination for this right-angle view was provided by Scotchlite, following the technique used in the main body of the chamber.<sup>12</sup> Initial at-

tempts to use propane as the sensitive media failed because propane attacked Scotchlite.

Griffin, and Frank Swartz, Bright-Field Bubble Chamber Illumination Using a Beaded Reflective Screen, UCRL-10861, July 1963.

12. Wilson M Powell, Larry Oswald, Gary

### DATA REDUCTION

Robert W. Birge and P. Wesley Weber

With a total of 17 (full-time equivalent) visual measurement personnel, the following data reduction was accomplished in the past 6 months:

Scanning			
Experiment	Bubble chamber	Beam	Number of Frames
<u>Conventional system</u>			
28	30-inch Freon	4.5-MeV/c K <sup>+</sup> , stopping	62 449
29	20-inch deuterium (Brookhaven)	3.69-BeV/c deuteron	71 261
30	72-inch hydrogen	3.94-BeV/c π <sup>-</sup>	2 360
32	25-inch hydrogen	850- to 1150-MeV/c K <sup>-</sup>	178 736
34	25-inch deuterium	850- to 1150-MeV/c K <sup>-</sup>	78 558
		Subtotal	393 364
<u>FSD system</u>			
30	72-inch hydrogen	3.94-BeV/c π <sup>-</sup>	2 219
32	25-inch hydrogen	850- to 1150-MeV/c K <sup>-</sup>	201 072
		Subtotal	203 291
		Total	597 655

Measuring				
Equipment	Measuring hours	Number of Vertices	Vertices per measuring hour	Measuring hours per 4032 hours
Microscope C	1143.8	6 040	5.3	0.26
Microscope E	2025.5	11 318	5.6	0.46
MP-1C	1691.0	8 869	5.2	0.39
Total	4860.3	26 227	5.4	0.37

PHYSICS RESEARCH

Emilio Segrè and Owen Chamberlain in charge

 $K^+$ -PROTON INTERACTIONS AT 2.7 BeV/c

Riley Newman, William Chinowsky, and Jonas Schultz

Analysis is in progress, in collaboration with W. Johnson and R. Larsen of Stanford University, of 50,000 pictures from the Brookhaven National Laboratory 20-inch hydrogen bubble chamber<sup>†</sup> exposed to a 2.7-BeV/c separated  $K^+$  beam. All film has been scanned twice. About 5,400  $K^+p$  events were found and measured, of the following topologies:

2-prong	≈3650 events	4-prong with V	20
2-prong with V	500	6-prong	12
4-prong	1000	3-prong ( $\tau$ decays)	185

A crude estimation at this point suggests a total  $K^+p$  cross section at this energy of about 25 mb, probably correct to 25%. At present only a small sample of each topology has been subjected to kinematical analysis--a sample sufficient to determine that analysis programs are operable. Classification of events awaits further analysis.

## PION BETA DECAY EXPERIMENT

Robert B. Bacastow,<sup>\*</sup> Claude Ghesquiere,<sup>†</sup> Clyde Wiegand, and Rudolf Larsen<sup>‡</sup>

The experiment has been completed. The data have been measured and analyzed and a manuscript for publication is in preparation. The following abstract was sent to the American Physical Society:

We have measured the branching ratio

$$R = (\pi^+ \rightarrow \pi^0 + e^+ + \nu) / (\pi^+ \rightarrow \mu^+ + \nu),$$

using spark chambers and scintillation counters. The conserved-vector-current theory predicts  $1.04 \times 10^{-8}$ ; our preliminary

result is  $(1.18 \pm 0.20) \times 10^{-8}$ , in good agreement with both the theory and several other recent experiments. The angle defined by the pion stop and the points of conversion of the two  $\gamma$ -rays from the  $\pi^0$  was reconstructed from the spark chamber pictures. The kinematic requirement that this angle be near  $180^\circ$  was found to be sufficiently restrictive to select 46 events with an estimated background of 6. The positron was detected in some of the events but was not required as part of the signature. The efficiency was measured by stopping  $\pi^+$ 's in a hydrogen gas target.

MEASUREMENT OF  $C_{NN}$  IN PROTON-PROTON SCATTERING AT 680 MeV

Helmut E. Dost, John F. Arens, Frederick W. Betz, Owen Chamberlain, Michel J. Hansroul, Leland E. Holloway, Claude H. Schultz, and Gilbert Shapiro

Using a polarized beam and polarized target, we have measured the spin-correlation parameter  $C_{NN}$  in proton-proton scattering for an incident proton laboratory-system kinetic energy of 680 MeV. The polarized beam was made by scattering unpolarized protons from the 184-inch cyclotron in an external first target of liquid hydrogen (giving 50% polarization) or carbon (for 35% polarization). To

reverse the beam polarization, the incident-proton scattering angle was reversed. The polarized second target was that described in reference 1. During the experiment it was typically polarized to 40%. The elastic proton-proton scatterings were kinematically separated from other interactions in the second target by counting both protons in coincidence. The angular region covered extended from about 55

\* University of California, Riverside.

† On leave from Ecole Polytechnique, Paris.

‡ Stanford Linear Accelerator Center

1. Claude H. Schultz, Scattering of 250-MeV  $\pi^+$  Mesons from a Polarized Proton Target (Ph. D. Thesis), UCRL-11149, Jan. 1964.

to 90 deg in the center-of-mass system. Preliminary analysis shows that  $C_{NN}$  has a value of about +0.5 throughout this region.

The above experiment, the first double-scattering experiment with a polarized target at high energies, was completed in June 1964. The data analysis is still in progress.

### K- $\Sigma$ PARITY

The authors of the abstract reproduced directly above, in collaboration with Byron D. Dieterle, Paul Grannis, David Weldon, Clairborne Johnson, and Herbert Steiner, are currently engaged in a measurement of the  $\Sigma$ -K intrinsic parity. In the process  $\pi^+ + p \rightarrow K^+ + \Sigma^+$ , with a polarized hydrogen target, an azimuthal asymmetry is expected whose magnitude is proportional to the target polarization and whose algebraic sign can be directly related to the  $\Sigma$ -K parity. The experiment involves 13 spark chambers in addition to the usual scintillation and Cerenkov counters. At the time of writing, data-taking is about to get under way.

Two 1000-cfm Roots booster pumps have been installed to pump on the liquid helium

temperature bath surrounding the polarized target, lowering the vapor pressure of the helium by a factor of 7 from its previous value. A significant rise in the target polarization is expected from this change.

A data-collection system of improved reliability, capacity, and versatility is being assembled for future experiments in p-p,  $\pi$ -p, and K-p scattering in which angular correlations of the final-state particles are used to identify the free-proton scattering events in the polarized target. The central feature of this system is a PDP-5 computer, used on-line to sort the events. Where possible, data will be taken simultaneously at all accessible angles with this system.

### SCATTERING OF 250-MeV POSITIVE PIONS BY PROTONS: EXPERIMENT AND ANALYSIS

Wladyslaw K. Troka, Frederick W. Betz, Owen Chamberlain,  
Gilbert Shapiro, and Claude Schultz

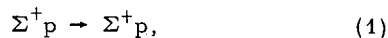
The differential cross section for elastic scattering of positive pions on protons has been measured at a nominal incident-meson kinetic energy of 250 MeV. The experiment was performed in 1962, but the data analysis was finished only recently. The angular range covered in the center-of-mass system by the 13 data points was 14.9 to 160 deg. The fractional rms errors were typically 1.5%. A liquid hydrogen target was bombarded by a beam of  $2.5 \times 10^6$  mesons/sec. The scattered pions were detected by a counter telescope. Recoil protons were eliminated by means of a Cerenkov counter.

A phase-shift analysis was performed which combined the above-mentioned data with the recoil-proton polarization measurements taken recently with the help of a polarized proton target. Only one acceptable SPD Fermi-type phase-shift set was found. When F waves were included, a total of three possible phase-shift solutions emerged from the analysis. However, arguments based on the data could still be made which eliminated all but one phase-shift set. One the other hand, the remaining phase-shift set, similar in type to the SPD solution, suffers from the disadvantage of large rms errors assigned to its small phase shifts.

### LOW-ENERGY HYPERON-PROTON INTERACTIONS

William Chinowsky, Robert R. Kinsey, W. Neal Rybicki, and Jonas Schultz

Approximately 2000 events have been measured thus far in an experiment to investigate the interactions of  $\Sigma$  hyperons and protons in the region of 5 to 10 MeV laboratory-system kinetic energy. The hyperons are produced by  $K^-$  stopping in the 30-inch Brookhaven-Columbia hydrogen bubble chamber. The reactions under study are



A large percentage of the measured events are  $\Sigma^-$ 's captured at rest, which provide an enormous source of background for reactions (2), (3), and (4). Based on a small sample of analyzed events, average cross sections for

Reactions (1) through (4) in this energy region are roughly 250, 150, 200, and 100 mb, respectively.

The measured events represent about 35%

of the scanned candidates for  $\Sigma$  interactions in flight. We estimate that there will be of the order of a few hundred genuine in-flight events by the time of completion of the experiment.

### MUON POLARIZATION AND ENERGY SPECTRUM IN $K^+ \rightarrow \pi^0 + \mu^+ + \nu$

Rae F. Stiening, David Cutts, and Tommy Elioff

In the reaction  $K^+ \rightarrow \mu^+ + \pi^0 + \nu$  we have measured the number of muons in the high-energy region of the continuum. The portion of the spectrum explored extended from 107.1 to 126.4 MeV muon kinetic energy. We also measured the longitudinal polarization of muons in the same energy interval by observing the spatial anisotropy of the  $e^+$  from muon decay. The  $\pi^0$  was not detected. The experiment was carried out with spark chambers and a Bevatron unseparated stopping  $K^+$  beam. We found the rate of decay with a muon in this energy interval to be  $0.054 \pm 0.008$  of the total  $K^+$  decay rate in the mode  $K^+ \rightarrow e^+ + \pi^0 + \nu$ . The polarization of the muons was found to be  $+0.61 \pm 0.39$ . These results are consistent with the assump-

tion of constant form factors. Assuming this, we have evaluated the form factor ratio  $\xi = f_2/f_1$  and find  $+0.65 < \xi < 1.8$ . An imaginary  $\xi$ , as proposed by Cabibbo,<sup>2</sup> is not excluded by this data provided that  $1.7 < |\xi| < 3.1$ . As a calibration experiment we measured the longitudinal polarization of muons from  $K^+ \rightarrow \mu^+ + \nu$  and found it to be  $-0.93 \pm 0.24$ , in agreement with the experiment of Coombes et al.<sup>3</sup>

2. N. Cabibbo, Phys. Letters 12, 137 (1964).
3. C. Coombes, B. Cork, W. Galbraith, G. Lambertson, and W. Wenzel, Phys. Rev. 108, 1348 (1957).



## PHYSICS RESEARCH

George H. Trilling and Gerson Goldhaber in charge

A STUDY of  $\pi^+ + p \rightarrow \omega^0 + N^{*++}$  AT 3.65 BeV/cJohn L. Brown, Gerson Goldhaber, Sulamith Goldhaber,  
John Kadyk, Benjamin Shen, and George Trilling

We have carried out a study of the  $\pi^+ + p$  interaction at 3.65 BeV/c giving five particles in the final state. The analysis of approximately 2000 events corresponding to the reaction  $\pi^+ + p \rightarrow \pi^+ + \pi^- + \pi^0 + \pi^+ + p$  shows that the majority of the events come from resonant channels. The preliminary cross sections for the dominant channels are (a)  $N^{*++}\pi^+\pi^-\pi^0 \approx 2$  mb, (b)  $\omega^0\pi^+p \approx 0.7$  mb, (c)  $N^{*++}\omega^0 \approx 0.7$  mb, (d)  $\eta^0\pi^+p \approx 0.05$  mb, (e)  $\eta^0N^{*++} \approx 0.04$  mb, with a total cross section of  $\approx 4.3$  mb. For the  $\omega^0$  and  $\eta^0$  the cross sections quoted refer to the  $\pi^+\pi^-\pi^0$  decay mode only. The decay angular distribution of the  $\omega^0$  and  $N^{*++}$  in channel (c)

shows that neither of the two resonances if strongly aligned, in contrast to the  $\rho^0N^{*++}$  final state, in which both resonances are produced in highly aligned states. A comparison of the experimental observation with single-particle exchange models is in progress. This experiment was carried out in the 20-inch Brookhaven National Laboratory's hydrogen bubble chamber, exposed in the Yale-Brookhaven separated beam at the alternating-gradient synchrotron (AGS). (This work was covered in UCRL-11724 Abs, submitted to the American Physical Society for the meeting in Berkeley, California, Dec. 1964.)

MULTIPARTICLE RESONANCES IN THE  $\pi^+p$  INTERACTION AT 3.65 BeV/c

Gerson Goldhaber, Sulamith Goldhaber, Thomas O'Halloran, Benjamin Shen, and Jan Dash

We are studying the resonance structures present in the four-particle final state of the  $\pi^+p$  interaction, i. e.,  $\pi^+ + p \rightarrow \pi^+ + \pi^- + \pi^+ + p$ . In addition to these dominant resonances, i. e.,  $\rho^0$ ,  $N_{3/2}^*(1238)$ , and  $f^0$ , we find finer effects involving possible interactions between three particles. These are (a) the  $A^+$  ( $A_1$  and  $A_2$ ) decaying into  $\rho^0 + \pi^+$ , (b) a  $p\pi^+\pi^-$  mass enhancement at 1480 MeV, and (c) a  $p\pi^+\pi^+$  mass enhancement at 1560 MeV. All above phenomena are associated with small momentum transfer to the multiparticle state. We also find a marked enhancement in the  $\pi^+\pi^-$  mass distribution at 390 MeV which is associated with the decay pions from the 1480-MeV  $p\pi^+\pi^-$  peak. We

thus interpret the  $\pi^+\pi^-$  (390 MeV) enhancement to be most likely due to a kinematic constraint. We are carrying out calculations to see whether we can reproduce the 1560-MeV mass peak, assuming the production of the double resonance  $N^{*++}\rho^0$  only when proper account is taken of the Bose symmetrization of the two  $\pi^+$  mesons. Preliminary results indicate that some of the qualitative features, e. g., a mass peak associated with small momentum transfer to  $p\pi^+\pi^+$ , can be reproduced by such a model. (This work was covered in UCRL-11445, submitted for the International Conference on High Energy Physics at Dubna, USSR, August 1964.)

 $\pi^-p$  INTERACTIONS AT 3.7 BeV/c

Sulamith Goldhaber, Gerson Goldhaber, Benjamin C. Shen, and George H. Trilling

We have completed the study of  $\pi^-p$  interactions at 3.7 BeV/c leading to four charged particles in the final state, viz  $\pi^- + p \rightarrow \pi^- + \pi^+ + \pi^- + p$ . The experiment was carried out in the 72-inch hydrogen bubble chamber. The measurements of the bubble chamber pictures were carried out with the flying-spot digitizer. We find the salient features of the interaction to be the following:

(a) Double-resonance formation of the neutral

$\rho$  with the neutral isobars  $N^{*0}(1238)$ ,  $N^{*0}(1510)$ , and  $N^{*0}(1688)$ . The observed energies,  $E$ , of the isobars and their respective estimated full widths at half maximum are given in Table I. (b) Strong asymmetries in the  $\pi^-_{in}$ ,  $\pi^-_{out}$  scattering angle in the  $\rho^0$  center-of-mass system. Part of this asymmetry can be explained to be due to interference effects produced by the presence of the 3/2, 3/2 nucleon isobar,  $N^{*++}(1238)$ .

Table I. Observed  $E$  and  $\Gamma$  values for the channels  $\pi^-p \rightarrow N^{*0} + \pi^+ + \pi^-$  and  $N^{*0} \rightarrow \pi^-p$

Isobar	$E_{\text{Observed}}$ (MeV)	$\Gamma$ (MeV)
$N_{3/2}^{*0}(1238)$	1220	120
$N_{1/2}^{*0}(1510)$	1480	120
$N_{1/2}^{*0}(1688)$	1690	100

(c) A mass enhancement in the  $N^{*0}\pi^+$  system

at 1520 MeV with a  $\Gamma = 240$  MeV. A clear increase in the density of points at the above-mentioned mass region is observed in a Dalitz plot corresponding to the three "particles,"  $N^{*0}(1238)$ ,  $\pi^+$ , and  $\pi^-$ . Since the "three-particle" mass crosses the  $\rho$  band, the observed  $\rho^0$  asymmetries may be due to interference effects with the  $(N^{*0}\pi^+)$  system.

(d) A strong anisotropy in the  $\pi_{\text{in}}^-$ ,  $\pi_{\text{out}}^-$  scattering angle in the  $(\pi^-\pi^-)$  center of mass. This observation may indicate either  $T=2$  d-wave scattering or the reflection of the effects discussed under (c).

(e) A summary of the estimate of partial cross sections, which is given in Table II.

Table II. Cross sections for the various channels in the reaction  $\pi^- + p \rightarrow \pi^+ + \pi^- + p + \pi^-$ .

Channel	Events	Cross section <sup>a</sup> (mb)
1. $N^{*0}(1238)$	50	} $0.085 \pm 0.025$ } $0.24 \pm 0.07$
$\rho^0 + N^{*0}(1510)$	44	
$N^{*0}(1688)$	46	
2. $\rho^0\pi^-p$ $\left\{ \begin{array}{l} A^-p \\ \rho^0\pi^-p \end{array} \right.$	160 <sup>b</sup> 130	290 } $0.27 \pm 0.08$ <sup>b</sup> } $0.50 \pm 0.15$
3. $N^{*++}\pi^-\pi^-$ $\left\{ \begin{array}{l} (p\pi^+\pi^-)\pi^- \\ N^{*++}\pi^-\pi^- \end{array} \right.$	90 170	260 } $0.15 \pm 0.05$ } $0.44 \pm 0.11$
4. $N^{*0}(1238)\pi^+\pi^-$ $\pi^+\pi^-\pi^-\pi^-$	340	$0.60 \pm 0.2$
-----		
Total	1030	$1.8 \pm 0.4$

a. All cross sections have been normalized to the total  $\pi^-p$  cross section.

b. The events in the  $A_1$  and  $A_2$  regions are included here.

(This work was covered in UCRL-11464 Abs., submitted to Dubna.)

K<sup>+</sup>d INTERACTIONS AT 2.3 BeV/c

John Brown, Ian Butterworth, Gerson Goldhaber, Sulamith Goldhaber, Allan Hirata,  
John Kadyk, Benjamin Shen, and George Trilling

A study of K<sup>+</sup>d interactions at a momentum of 2.3 BeV/c has been carried out with the Brookhaven National Laboratory 20-inch bubble chamber exposed at the AGS. Production processes in the reactions

$$K^+d \rightarrow K^{*0}pp \quad (1)$$

and

$$K^+d \rightarrow K^{*+}pn \quad (2)$$

have been compared. In reaction (1) the K $\pi$  scattering angle  $\alpha$  in the K<sup>\*</sup> center of mass shows a predominantly  $\cos^2\alpha$  distribution, while the angle  $\gamma$  between the outgoing K meson and the production plane in the K<sup>\*</sup> center of mass is distributed predominantly as  $\sin^2\gamma$ . In reaction (2) the reverse is true. This indicates the presence of pseudoscalar and vector exchange respectively. The distribution in four-momentum transfer is narrower for reaction (1)

than for reaction (2).

Evidence has been found for the reactions

$$K^+d \rightarrow K^0\pi^+d$$

and

$$K^+d \rightarrow K^+\pi^-\pi^+d$$

at low momentum transfer to the deuteron. The former reaction almost exclusively involves K<sup>\*+</sup> production, the distribution of the angles  $\alpha$  and  $\gamma$  indicating vector exchange. For such a reaction the exchanged particle must have zero isotopic spin and is presumably the  $\omega$  meson. At the present level of statistics no particular structure is evident in the K $\pi\pi$  effective-mass distribution for the second reaction.

(This work was covered in UCRL-11769 Abs., submitted to Berkeley APS meeting, Dec. 1964.)

K<sup>+</sup>p AND K<sup>+</sup>d EXPERIMENT AT 860 TO 1600 MeV/c IN THE 25-INCH HYDROGEN-DEUTERIUM BUBBLE CHAMBER

Roger W. Bland, Michael G. Bowler, John L. Brown, Ian Butterworth, Gerson Goldhaber, Sulamith Goldhaber, John A. Kadyk, Victor H. Seeger, and George H. Trilling

In the period March to September 1964 the LRL 25-inch hydrogen-deuterium bubble chamber was exposed in a separated K<sup>+</sup> beam at a series of momenta between 860 MeV/c and 1600 MeV/c. Approximately 350 000 pictures were taken in hydrogen and 150 000 in deuterium. The majority were taken in the so-called "double-pulse" mode, in which two pictures are taken during each Bevatron pulse, with a time separation of about 300 msec. The current status of the analysis of these pictures is outlined below.

## A. Preliminary Cross-Section Survey

In order to make a survey of the cross sections for various channels as a function of in-

cident K<sup>+</sup> momentum, a small sample of film was carefully double-scanned and measured. The results are presented in Table III below. A similar survey is underway in the deuterium film.

(This work was covered in UCRL-11446, submitted for the International Conference on High Energy Physics at Dubna, USSR, Aug. 1964.)

B. Single Pion Production by K<sup>+</sup> Mesons at 960 MeV/c

Some 9000 interactions in hydrogen of K<sup>+</sup> mesons of momentum 960 MeV/c have been measured with the "flying spot digitizer." We are currently analyzing the inelastic events in

Table III. K<sup>+</sup>-p partial cross sections (in mb) as a function of incident K<sup>+</sup> momentum

Reaction	Incident K <sup>+</sup> momentum (MeV/c)				
	860	960	1200	1360	1580
$\sigma(K^+p \rightarrow K^+p)$	12.6 ± 0.7	11.5 ± 0.8	10.9 ± 0.7	8.7 ± 0.6	9.6 ± 1.0
$\sigma(K^+p \rightarrow K^0p\pi^+)$	0.9 ± 0.2	2.8 ± 0.4	4.4 ± 0.4	5.8 ± 0.5	5.6 ± 0.8
$\sigma(K^+p \rightarrow K^+p\pi^0)$	0.4 ± 0.1	0.8 ± 0.2	2.1 ± 0.3	2.1 ± 0.3	0.9 ± 0.3
$\sigma(K^+p \rightarrow K^+n\pi^+)$	0.1 ± 0.1	0.2 ± 0.1	0.7 ± 0.2	0.9 ± 0.2	1.3 ± 0.4

which a single pion is produced, a sample of some 1500 events. The final states are  $K^+\pi^+n$ ,  $K^+\pi^0p$ , and  $K^0\pi^+p$ . Formation of the nucleon-pion resonance  $N^*(1238)$  dominates all these channels. The absence of competing inelastic reactions makes this incident momentum particularly suitable for a study of the detailed dynamics of  $N^*(1238)$  production. A preliminary analysis indicates that  $N^*(1238)$  production can be understood in terms of single  $\rho$ -meson exchange, without requiring the introduction of empirical form factors.

#### C. Four-Particle Final States at 1580 MeV/c

We have studied the reaction  $K^+p \rightarrow K^+p\pi^+\pi^-$  for incident  $K^+$  of 1580 MeV/c momentum. On the basis of a partial sample of events, strong

$N^*(1238)$  MeV) formation was observed, as well as some  $K^*(890)$  MeV) formation. Although this beam energy is below threshold for double resonance production,  $K^* + N^*$ , at the nominal resonance values, a large part of the reaction proceeds via this channel through the tails of the resonance distributions. There is a considerable shift in the position of both resonance peaks and a reduction in width of the  $N^*$  distribution. The double-resonance formation is presumably the explanation of these observations. An analysis is under way to determine the cross section of this reaction and the related reaction  $K^+p \rightarrow K^0p\pi^+\pi^0$ , and to study the dynamics of these processes.

(This work was covered in UCRL-11720 Abs., submitted to Berkeley APS Meeting, December 1964.)

DATA HANDLING

Howard S. White in charge

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

## ACCELERATOR OPERATION AND DEVELOPMENT

### ACCELERATOR STUDY GROUP

Edward J. Lofgren in charge

Reported by Gilbert F. Rankin, Jr.

The design study for the 200-GeV accelerator is continuing, as authorized by the Atomic Energy Commission. After exploration of feasible alternatives, decisions on major machine parameters have been reached.

Effort on the study was reduced slightly at the beginning of fiscal year 1965, and has aver-

aged about 57 people since July 1.

The National Advisory Committee for the design study has met three times during the period of this report. The Committee has concerned itself with organizational plans for the accelerator laboratory, and has conferred with study group members on technical progress.

### ACCELERATOR PARAMETERS

Reported by Francis T. Cole

The following general parameters and features of the accelerator have been fixed:

1. Energy - 200 GeV.
2. Intensity -  $3 \times 10^{13}$  protons per pulse to be achieved in present configuration. Ultimate capacity of accelerator is to be  $10^{14}$  protons per pulse.
3. Repetition rate - maximum of 30 pulses per minute. Provision will be made for a 0.6-sec flat top to give a minimum of 23 pulses per minute.
4. Injection - 8-BeV rapid-cycling synchrotron, which has an injection energy of 200 MeV.
5. General layout - a sketch of the proposed accelerator and experimental area layout is shown in Fig. 1.

#### Theory

Parameter studies carried out by the theory group (A. A. Garren) have led to a final decision on the main ring structure. It will contain 12 long (Collins) straight sections, giving an effective accelerator radius of 702 m. Extensive studies of even longer straight sections did not develop a clear need for more straight-section length.

#### Magnet Design

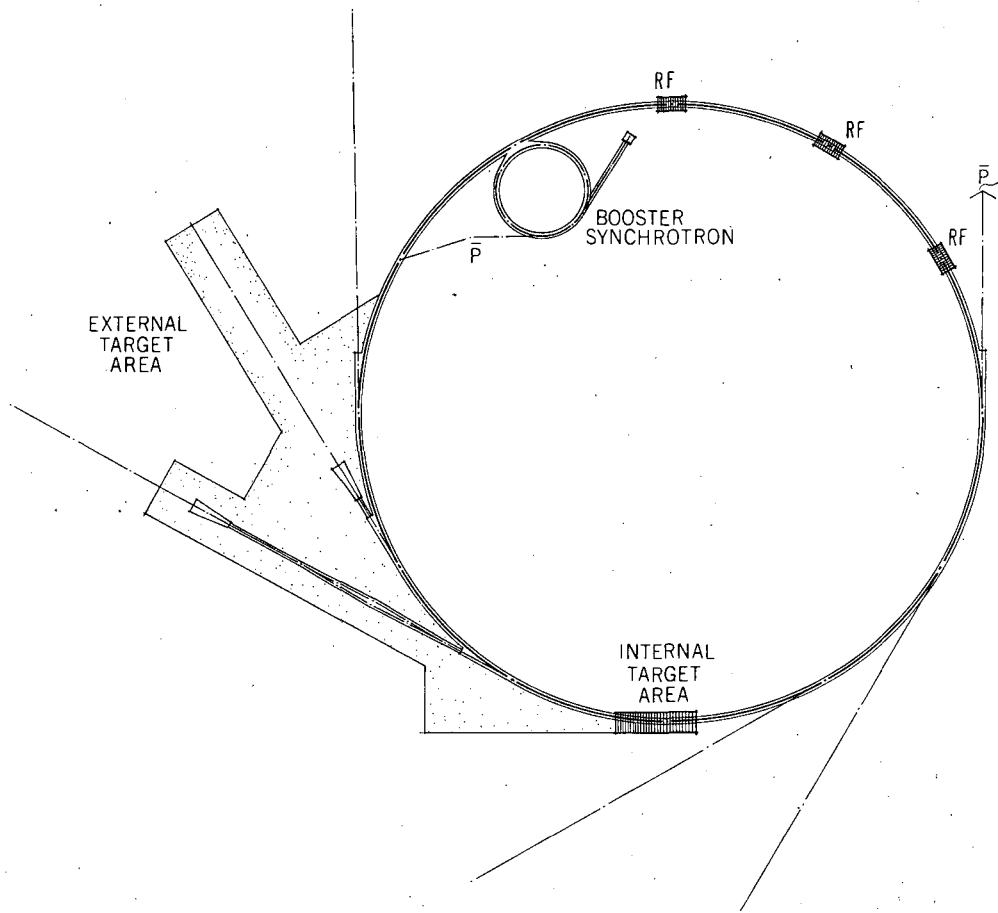
A "C" magnet yoke design similar to those at CERN and BNL has been chosen. The exciting coils will be flat pancakes of rectangular cross section, tilted from the horizontal plane as in the DESY electron synchrotron. (Charles G. Dols and Robert A. Kilpatrick) The aperture

within the vacuum chamber has been chosen as 12 cm horizontal by 5 cm vertical. Computations (Joseph H. Dorst) show that this design will achieve 15 kilogauss at the central orbit, with a decrease in gradient due to saturation of less than 4% at the central orbit and of approximately 11% at the edge of the chamber. Corrections for these gradient changes will be provided by quadrupole and sextupole magnet lenses in straight sections between magnets.

#### Injection

The choice of 8 BeV for the output energy of the injector synchrotron (booster) was made after extensive cost optimization (Jack M. Peterson and H. Paul Hernandez) and space charge studies (Jack M. Peterson and L. Jackson Laslett). There is a broad cost optimum for the guide field around 7 kilogauss peak. This is definitely lower than the optimum field for the main ring guide; the difference arises from the relatively high cost of storage of the guide-field energy in the resonant power supply of the rapid-cycling injector.

The choice of injection energy into the booster is again affected by cost and intensity considerations. The choice of 200 MeV will achieve the desired intensity with an adequate safety factor, and will not require a change in the structure of the linear accelerator. Approximately three turns of protons will be injected into the booster to achieve the desired intensity. (Edward L. Hubbard)



MUB-4631

Fig. 1. Sketch of proposed accelerator and experimental area layout.

The filling time of the main ring and the associated repetition rate of the booster are still under study.

The booster structure will contain 16 long (Collins) straight sections, giving an effective accelerator radius of 100.3 m (Frank B. Selph and A. A. Garren), to accommodate injection and extraction mechanisms and the rf cavities to give the necessary rapid acceleration. The booster aperture will be approximately 14 cm horizontal by 7 cm vertical.

It is planned (Denis Keefe) to use one of the long straight sections as a test facility for experimental equipment, which will use beam accelerated when the booster is not performing its primary function as an injector. It is also planned (Denis Keefe) to leave straight-section space so that at some time in the future the booster can be used to store 8-BeV antiprotons produced by main-ring protons. These antiprotons will then be injected into the main ring and accelerated. It is estimated that a mono-

energetic beam of more than  $10^5$  antiprotons will be available at energies up to 200 BeV.

#### Radio Frequency

Harmonic numbers have been chosen so that protons will be accelerated in the booster over a frequency range from approximately 25 Mc/sec at injection to 50 Mc/sec at final energy. Particle bunches from the booster will be transferred directly into main-ring buckets and accelerated at approximately 50 Mc/sec. This frequency range is appropriate for the ferrite tuning systems that have been chosen, and appear to be appropriate for beam-sensing devices. An extensive program of ferrite evaluation is being carried out. (Quentin A. Kerns)

#### Magnet Power Supplies and Electricity Distribution

Design work on the main-ring power supply (Fritz Grütter) has led to the choice of motor-alternator sets with silicon-controlled recti-

fiers. The guide-field energy is to be stored in flywheels.

Design of the booster magnet power supply (Fritz Grütter) has followed the experience at CEA (Cambridge electron accelerator), PPA (Princeton-Penn Accelerator), and DESY (Deutsches Elektronen-Synchrotron). A resonant system with energy storage in condenser banks and distributed chokes is planned. The field is biased so that injection occurs at the bottom of the sine wave.

Schematic designs for the electrical distribution system have been worked out (Fritz Grütter). It is planned that roughly half of both the external beam and the experimental magnets will be pulsed to save power. The pulsed power will be distributed in experimental areas

by a separate system electrically isolated from the CW system.

#### Shielding and Radiation Protection

A series of experiments to measure residual induced radioactivity levels at the BNL-AGS (William S. Gilbert) has permitted more accurate estimates of the induced activity that is to be expected in the proposed accelerator. Measures that can help to localize this activity include use, for constructing the main-ring enclosure walls, of aggregate with low sodium content and with boron added. There are still major effects on the design of components to permit their maintenance and repair in high-activity surroundings. These problems are under intensive study at this writing.

### SITE AND FOUNDATION

Reported by Harold A. Wollenberg

At the Camp Parks site, geodetic networks were established in April - May, involving:

- (a) large-area triangulation and baseline measurement, to detect broad-scale horizontal movements;
- (b) precise triangulation, taping, and leveling over quadrilateral figures, spanning the Pleasanton and Calaveras faults, to detect possible strain accumulation along the faults;
- (c) leveling traverse from area of subsidence near Pleasanton across the Parks fault and into Camp Parks area, to check the hypothesis that the Parks fault dissociates Camp Parks from the subsiding area, and to establish a leveling net over areas of interest.

Items (b) and (c) require remeasurement before any results can be obtained; large-area triangulations (a) are presently being compared with 1947 measurements.

Results of continuous seismic monitoring at Camp Parks are being related to data from the U. C. seismographic network. This will ultimately yield empirical relationships between ground motion and wave periods, and also give magnitude and epicentral distance of seismic events.

Preliminary evaluation of soil-test data by Dr. Phillip Rutledge indicates that pile settlement in the area of deep cuts would be 0.01 in. during the first year after accelerator alignment; the housing would settle about 0.1 in. In areas of minimum cut, pile settlement would also be about 0.01 in. during the first year after alignment, and the housing settlement about 0.15 in.

A site being studied in the Sierra foothills occupies an area of low relief underlain by metamorphosed sedimentary and volcanic rocks. These furnish a firm foundation requiring no appreciable pile support. Maximum depth of cuts would be on the order of 40 ft as opposed to 100 ft at Camp Parks. Cut slopes could probably stand on 1:1. At least 50% of the excavation would require drilling and blasting, making this material about twice as expensive to excavate as the material at Parks. There are no active faults on or near the site. The seismic response of the ground is small: ground amplitudes would be 1/2 to 1/3 those of Parks-like material for earthquakes at comparable epicentral distances. Areas of active seismicity are more than 100 miles distant.



BEVATRON

Edward J. Lofgren in charge

Reports on Bevatron Operation and Development are issued on a quarterly basis. The report to cover the period April-June 1964 (Report No. 42) is to appear as UCRL-11737, Nov. 1964; the report for July-September (No. 43) is being prepared, but has not yet been issued.

184-INCH CYCLOTRON

Robert L. Thornton in charge

Reported by James T. Vale

The time that the operating crew was on duty was divided as follows: 94% used for research experiments; 2.5%, routine maintenance; 3.5%, component failures. The 184-inch cyclotron ran quite well during this period, with a minimum of outage.

A large number of shielding blocks has been acquired during this period. Some of them have been installed in present experimental setups, and the rest are waiting for appropriate times for their installation.

A small cyclotron of 28-inch-diameter pole piece has just been completed. This is purely a model for the study of starting conditions of ions in cyclotrons, with the idea that information gained here could be applied to the 184-inch cyclotron or to any other similar machine. It was decided to conduct this study in a model rather than the full-scale machine because of

the high radioactive level in the 184-inch cyclotron. This high level makes it impossible for any one person to be inside the 184-inch longer than a few minutes per week. Thus the difficulties of working in the 184-inch cyclotron are readily apparent.

Thus far the 28-inch model has just barely been put in operation. The attempt will be to do as much of the investigation as possible at small radii and at small duty cycles to keep the radiation level low. The duty cycle at present is approximately 1%, and the probe has been used at a 6-in. radius. The average beam current under these initial conditions is somewhat more than a microampere.

This investigation was prompted by suggestions from Dr. Kenneth MacKenzie of UCLA, and is to be conducted jointly by him and the Laboratory here.

HEAVY-ION LINEAR ACCELERATOR

Robert M. Main

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

88-INCH CYCLOTRON

Homer E. Conzett in charge

## OPERATION

The distribution of cyclotron time during the period May 1964 through October 1964 was:

	<u>8-hr shifts</u>	<u>%</u>
Physics research	234	41
Isotope production (104 targets delivered)	110	20
Biomedical research	22	4
Cyclotron research and development	43	8
Preventive maintenance and scheduled shutdowns	118	21
Repairs (scheduled time lost)	<u>32</u>	<u>6</u>
Total	555	100

The external beam current is still limited by septum heating, which restricts the beam power at extraction radius to about 2 kW.

A persistent vacuum leak at the ion-source (to) pole-tip gasket was located and fixed; the operating tank pressure has been reduced from  $3 \times 10^{-5}$  to  $7 \times 10^{-6}$  torr, with a resultant improvement in rf and dc voltage holding capabilities. Heating in the resonator tank at frequencies above 14 Mc/sec has been reduced by replacing iron structural members with non-magnetic material.

## NUCLEAR PHYSICS

1. Studies of elastic and inelastic helium-ion scattering have been extended to several targets and to the broad energy range available.
2. Equipment for measurements of correlations between charged particle and gamma rays has been set up and tested.
3. Measurements have been made of proton polarization in p-d and p-He<sup>4</sup> elastic scattering.
4. Studies of  $\alpha$ - $\alpha$  scattering have been extended to the range 23 to 54 MeV.
5. Preliminary results have been obtained which show the effects of final-state interactions in the reaction He<sup>3</sup>(d,t)2p.
6. The (p,t) and (p,He<sup>3</sup>) reactions induced by 43.7-MeV protons on several light nuclei have populated isotopic spin T = 1 and T = 2 states not previously seen.
7. Studies of angular correlations of fission fragments emitted from U<sup>238</sup> and Pu<sup>240</sup>, excited by inelastic alpha-particle scattering, have been carried out.
8. Mass and energy correlations in fission of Ta, Au, and Bi induced by  $\alpha$  particles have been determined.

Detailed reports describing experimental results are contained in the current Chemistry Division Annual Report.

## CYCLOTRON RESEARCH AND DEVELOPMENT

A pilot-model beam regenerator was built and tested. It produced a 0.2-in. turn separation at extraction radius. A regenerative deflection system has been designed and is under construction. This system promises substantial improvement in deflection efficiency (presently 30 to 40%), in addition to reduction of the energy spread in the external beam (now about 0.5%).

The development of an external-beam phase probe has made it possible to examine the distribution of beam within a single rf pulse. This instrument, when used with an energy detector, has provided information on the structure of the external beam with respect to both time and energy.

ELECTRON LINEAR ACCELERATOR

Edward J. Lofgren in charge

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

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