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PHYSICS DIVISION SEMIANNUAL REPORT

May through October 1965

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UNIVERSITY OF CALIFORNIA  
Lawrence Radiation Laboratory  
Berkeley, California  
AEC Contract No. W-7405-eng-48

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Work done under the auspices of the U. S. Atomic Energy Commission

Printed in USA. Price \$3.00. Available from the Clearinghouse for Federal  
Scientific and Technical Information, National Bureau of Standards,  
U. S. Department of Commerce, Springfield, Virginia.

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## PHYSICS DIVISION SEMIANNUAL REPORT

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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):

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## RESEARCH WITH BUBBLE CHAMBERS

Associated Production Experiment

Between mid-1960 and mid-1961, the 72-inch hydrogen bubble chamber was exposed to  $\pi^+$  and  $\pi^-$  beams at six laboratory momenta from 1.030 to 1.325 BeV/c. About 1 000 000 pictures were taken, of which 3/4 have been analyzed at Berkeley and the remainder at the University of Wisconsin and at Purdue, Johns Hopkins, and Duke Universities. Numerous results from this experiment have been published. In late 1964 an additional 110 000 pictures of  $\pi^-$  incident at five different momenta from 0.910 to 1.030 BeV/c were taken for analysis at Berkeley.

Hyperon Production and Decay

Study of the reactions  $\pi^-p \rightarrow \Lambda K^0$ ,  $\pi^-p \rightarrow \Sigma^- K^+$ , and  $\pi^-p \rightarrow \Sigma^0 K^0$  with the  $\pi^-$  incident at 1.170 BeV/c has been continued, as has the investigation of the reaction  $\pi^-p \rightarrow \Lambda K^0$  with the  $\pi^-$  incident at momenta below 1.030 BeV/c (the threshold for  $\Sigma$  production). Study of n-p scatterings in which the neutrons come from  $\Sigma^+$  or  $\Sigma^-$  decay, together with the known  $\Sigma^+$  polarization, yields an estimate of the parameters  $\gamma$  for  $\Sigma^+$  and  $\Sigma^-$  decay. (FSC, JAA, JCD)

### Production of $\eta$ Mesons

The analysis of 41  $\pi^+p \rightarrow \pi^+\eta$  events at 1.050 BeV/c and of 113  $\pi^+p \rightarrow \pi^+\eta$  and 64  $\pi^-p \rightarrow \pi^-\eta$  events at 1.170 BeV/c is near completion. Cross sections have been obtained. The production Dalitz plots show concentrations which may be interpreted either as  $N^*(1238)$  formation or as an  $\eta p$  enhancement near threshold. On the assumption that the effects are not due to an  $\eta p$  enhancement, the data are consistent with s- and p-wave production of the  $\eta(\pi p)$  system and s- and p-wave decay of the final  $\pi p$  system. Recent experiments on  $\eta$  production in the reaction  $\pi^-p \rightarrow \eta n$  indicate the possible existence of an  $\eta N$  resonance near threshold for the reaction. Properties of the resonance (if it exists) are as yet unknown. The consistency of such a resonance with our data is being investigated. (RAG, FSC)

### Decay Modes of the $\eta$ Meson

In collaboration with other groups at Berkeley, the University of Wisconsin, and Columbia and Yale Universities, a compilation has been made of 1500 events in which  $\eta \rightarrow \pi^+\pi^-\pi^0$ . An asymmetry between  $\pi^+$  and  $\pi^-$  energy distributions would indicate that C invariance is not being preserved. Detailed subtractions of background and corrections for "ambiguous pions" have been made. The corrected data are, within the limits of statistics, quite consistent with preservation of C invariance.

Analysis of the decay mode  $\eta \rightarrow \pi^+\pi^-\gamma$  is nearly complete. The branching ratio has been determined. Possible asymmetries between  $\pi^+$  and  $\pi^-$  energy distributions are being

investigated. It has been suggested that the decay  $\eta \rightarrow e^+e^-\pi^0$  might occur if C invariance were not preserved. A reexamination of 9 000 four-prong events gives an upper limit  $\frac{\eta \rightarrow e^+e^-\pi^0}{\eta \rightarrow \gamma\gamma} \leq (0.7 \pm 0.7) \times 10^{-2}$ . (FSC, LRP, MLS)

### Leptonic Decays of Neutral K Mesons

A sample of 34 leptonic  $K^0$  decays has been obtained from the  $\pi^+p \rightarrow \Lambda K^0$  events. Preliminary analysis indicates no disagreement with the  $|\Delta I| = 1/2$  rule or with the  $\Delta S = \Delta Q$  rule. R. G. Sachs (University of Wisconsin) has suggested that CP violation in leptonic decays might explain CP mixing in  $K_2$  decays. The explanation requires that the decay amplitudes be related by  $a(K^0 \rightarrow e^-\pi^+\bar{\nu}) \approx \pm ia(K^0 \rightarrow e^+\pi^-\nu)$ . The observed time distributions are consistent with this relation but do not demand it. Sachs has also suggested a test for CPT violation. The observed time distributions are consistent with CPT invariance. (FSC, RLG)

### The $K_1, K_2$ Mass Difference

The data reduction of interactions of neutral K mesons has been completed. There are 70 hyperon-production events, 14 charge-exchange events, and 31 elastic scatterings. Analysis of the hyperon events gives the magnitude of the mass difference,  $|m_2 - m_1|$ , to be  $(0.62^{+0.37}_{-0.31}) \times \tau_1^{-1}$ . The charge-exchange events are being analyzed to test the mixing parameters of the neutral K-meson system. The elastic scatterings are being analyzed to determine the sign of the  $K_1, K_2$  mass difference. (FSC, GWM)

### K72 Experiment

This was an exposure, totaling 14 000 events/mb, of the 72-inch hydrogen bubble chamber to a  $K^-$  beam having laboratory-system momenta of 1.05, 1.11, 1.22, 1.33, 1.42, 1.51, 1.60, and 1.70 BeV/c. The film was between October 1961 and June 1962. A number of results have been published. Most of the projects reported here are completed and will shortly appear in print.

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

The completed analysis yielded 4000 examples of the first reaction and 7 000 examples of the second. Effects of peripheral production are evident in both channels. Furthermore, the behavior of the differential cross sections and (for the second reaction) polarizations as functions of energy gives

substantial evidence for the existence of a  $Y^*$  with the following properties:  $m = 2060$  MeV,  $\Gamma = 180$  MeV, elasticity  $x = 0.35$ , and  $(I, J^P) = (1, 7/2^+)$ . This has the quantum numbers of the recurrence of the  $Y_1^*(1385)$  and presumably belongs to a decuplet containing also the  $N_3^*/2(1920)$ . (FTS, MLS, CGW)

### The Reactions $K^-p \rightarrow \Sigma^\pm \pi^\mp$ and $K^-p \rightarrow \Sigma^\pm \pi^\mp \pi^0$

Of the two-body reactions, 5036 events fit  $\Sigma^+\pi^-$  and 2322 events fit  $\Sigma^-\pi^+$ . Both cross sections show some structure in the region of the  $Y_1^*(2060)$ . Both  $\Sigma^+$  and  $\Sigma^-$  production angular distributions display sharp peaking in the backward direction. When fitted to a Legendre polynomial series, the angular distributions for  $\Sigma^-$  require terms through  $P_6$ . The  $\Sigma^+$  distributions are not easily fitted to

Legendre polynomial series because  $K^*$  exchange is present. The forward-produced  $\Sigma^+$  show large polarization. Of the three-body reactions, 5240 events fit  $\Sigma^+\pi^-\pi^0$  and 4400 events fit  $\Sigma^-\pi^+\pi^0$ .  $Y_0^*(1405)$ ,  $Y_0^*(1520)$ ,  $Y_1^*(1385)$ ,  $Y_1^*(1660)$  hyperons and probably  $\rho$  mesons are produced. Cross section and angular distributions for the various processes are being studied. (ABG, MHA, AHR)

#### The Reaction $K^-p \rightarrow \Lambda\omega$

Total cross sections for  $K^-p \rightarrow \Lambda\omega$  with  $\omega \rightarrow \pi^+\pi^-\pi^0$  are as follows:

1.33 BeV/c	$0.80 \pm 0.06$ mb
1.42	$0.97 \pm 0.08$
1.51	$0.96 \pm 0.05$
1.60	$0.78 \pm 0.05$
1.70	$1.01 \pm 0.06$

The entire set of possible angular correlations for various regions of center-of-mass energy and momentum transfer has been determined. Production amplitudes have been determined from the angular correlations. Study of the correlations indicates that no simple exchange model provides a full description of the process. (PE, SMF, DOH, JBS, FTS, MLS)

#### Decay Modes of the $\omega$ Meson

The decay of  $\omega$  mesons produced in the reaction  $K^-p \rightarrow \Lambda\omega$  has been studied. If  $\Gamma(\pi^+\pi^-\pi^0)$ , the rate of decay into  $\pi^+\pi^-\pi^0$ , is set equal to 1, then  $\Gamma(\text{neutrals}) = 0.096 \pm 0.016$ ,  $\Gamma(\pi^+\pi^-\gamma) < 0.05$ ,  $\Gamma(\eta\pi^0) < 0.017$ ,  $\Gamma(\eta\gamma) < 0.017$ , and  $0.03 \leq \Gamma(\pi^+\pi^-) \leq 0.08$ , depending on the degree of coherence between  $\omega$  and  $\rho$  decay. C conservation has been tested by looking for an asymmetry between  $\pi^+$  and  $\pi^-$  in the  $\pi^+\pi^-\pi^0$  decay mode. The decay distributions are consistent with the simplest matrix element for the decay of a  $1^-$  meson. A quite fortuitous combination of form factors would be required for the spin-parity of the  $\omega$  to be  $3^-$ . (SMF, DOH, JJM, JBS, FTS, MLS, CGW)

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

From the whole experiment a sample of 1004  $\Xi^-$  and 206  $\Xi^0$  was obtained. From threshold (1.05 BeV/c) to 1.7 BeV/c, cross

sections rise to about 150  $\mu\text{b}$  for  $\Xi^-K^+$  production and to about 100  $\mu\text{b}$  each for  $\Xi^0K^0$  and  $\Xi\pi K$  production. Production of the  $\Xi^*(1530)$  is observed at the higher momenta, and the assignment  $I = 1/2$  for it is confirmed. The  $\Xi$ -decay analysis yields weak evidence for  $J_\Xi = 1/2$ . When  $J_\Xi = 1/2$  is assumed, decay parameters are  $\alpha_{\Xi^-} = -0.368 \pm 0.057$  and  $\Phi = \tan^{-1}(\beta/\alpha)_\Xi = 0.008 \pm 0.188$  radian. This leads to a final-state  $\pi\Lambda$  phase shift ( $\delta_s - \delta_p$ ) of  $-1 \pm 26$  deg. No significant violation of the  $\Delta I = 1/2$  rule is observed. The upper limit on the leptonic decay rate ( $\Xi^- \rightarrow \Lambda e^- \bar{\nu}$ ) / ( $\Xi^- \rightarrow \Lambda \pi^-$ ) is 0.5%. (JPB, PE, JRH, DWM, JBS, FTS, MLS)

#### Lambda Interactions in Hydrogen

About 150  $\Lambda$  interactions have been obtained from the K72 experiment and 90 from the K63 experiment. The  $\Lambda$  lab momenta range from 0.4 to 1.5 BeV/c. About half the reactions are elastic scatterings. Analysis of other reaction channels is difficult, but constraints imposed by charge independence help determine different cross sections. (MHA, JRH)

#### The Reactions $K^-p \rightarrow K^-p$ , $K^-p \rightarrow K^-p\pi^0$ , and $K^-p \rightarrow K^-n\pi^+$

The rapid rate at which the Spiral Reader, compared with other machines, can measure (see Data Reduction Development: Spiral Reader System) makes practical the analysis of the most numerous of the topologies seen in the bubble chamber, the two-prong events. The major channels hitherto neglected in the analysis of the K72 and K63 experiments are the reactions  $K^-p \rightarrow K^-p$ ,  $K^-p \rightarrow K^-p\pi^0$ , and  $K^-p \rightarrow K^-n\pi^+$ . Measurements of about 100 000 events distributed over nine momenta from 1.4 to 2.7 BeV/c are nearing completion. The analysis of the elastic scatterings bears on the existence and properties of  $Y^*$  resonant states in the direct or s channel, in particular on the properties of the  $Y^*(2060)$ . Furthermore, a knowledge of the characteristics of elastic scattering is essential to an analysis of other two-body reaction channels in terms of the peripheral model with absorption. In the three-body final states mentioned above, the production of  $N^*$ ,  $Y^*$ , and  $K^*$  resonant states will be investigated. (GRL, LJJL)

#### K63 Experiment

This was an exposure, totaling 30 000 events/mb, of the 72-inch hydrogen bubble chamber to a  $K^-$  beam having lab momenta of 1.70, 2.10, 2.45, 2.58, 2.63, and 2.70 BeV/c. Exposures with deuterium in the chamber were taken at 2.1 and 2.7 BeV/c, and a run was made at 2.1 BeV/c with a lead plate in the

chamber to convert  $\gamma$  rays and thus detect neutrals. The film was taken between mid-1963 and early 1965.

[See also the last two abstracts of the preceding section (K72 Experiment).]

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

Study of this reaction for lab momenta of 2.1 BeV/c and higher is continuing. The following resonances in the final state are observed at all the momenta:  $Y^*(1660)$ ,  $Y^*(1765)$ ,  $N^*(1238)$ ,  $N^*(1518)$ ,  $N^*(1688)$ , and  $K^*(892)$ . Cross sections for the production of these states as functions of energy have been calculated by use of a maximum-likelihood method. Programs have been developed to make these fits; these allow parameters of the resonances to be varied. Differential cross sections and spin-density matrix elements for  $K^*$  production have been determined and are being compared with predictions of the peripheral model with absorption. (JHF, RRR)

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

$Y^*(1385)$ ,  $\rho$ , and  $\omega$  are produced copiously in this reaction and the quasi-two-body final states  $\Lambda \omega$  and  $Y^* \rho$  are seen. Maximum-likelihood fits have been made to determine cross sections and production angular distributions for  $Y^{*+} \rho^-$ ,  $Y^{*0} \rho^0$ ,  $Y^{*-} \rho^+$ , and  $\Lambda \omega$ . Some 8000 events have been processed in this manner, and it is expected that continuing analysis will yield a determination of the mass differences between  $Y^{*+}$ ,  $Y^{*0}$ , and  $Y^{*-}$ . (JHF, RRR, DMS)

### The Reaction $K^-p \rightarrow \Lambda \omega$

A preliminary analysis of the decay angular correlations in the reaction  $K^-p \rightarrow \Lambda \omega$ ,  $\Lambda \rightarrow p \pi^-$ ,  $\omega \rightarrow \pi^+ \pi^- \pi^0$  has been carried out. The results are inconsistent with predictions of simple exchange models. An application of the peripheral model with absorption is planned. Preliminary cross sections for the reaction, equal to about 200  $\mu\text{b}$  between 2.45 and 2.70 BeV/c, give no evidence for effects that could be attributed to unusual behavior in the direct or s channel. (SMF, MLS)

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

Work on these reactions is continuing. From 2.1 to 2.7 BeV/c the cross sections decline by a factor of approximately 2. Both reaction differential cross sections are strongly peaked in the forward direction. Peripheral mechanisms appear to dominate both processes, but predictions according to the simplest models are not adequate. (ABG, FS, RDT)

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

Thus far some 15 000 events with two prongs and a subsequent decay of one of them have been measured. The final states  $\Sigma^\pm \pi$ ,  $\Sigma^\pm \pi \pi^0$ , and  $\Sigma^\pm \pi \pi^\mp +$  (missing neutrals) are

being studied. Some preliminary cross-section values have been determined. The Dalitz plots of the three-body final states show production of  $Y^*(1405)$ ,  $Y^*(1520)$ ,  $Y^*(1660)$ , and  $\rho$ . (ABG, RKB, PE, FS)

### Study of the $\eta'$ (958 MeV)

Collection and analysis of data is proceeding for the reaction

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

followed by  $\Lambda \rightarrow p + \pi^-$

$$\text{and } \eta' \rightarrow \eta + \pi^+ + \pi^-, \quad \begin{array}{l} \eta \rightarrow \pi^+ + \pi^0 + \pi^- \\ \eta \rightarrow \pi^+ + \pi^- + \gamma \\ \eta \rightarrow \text{neutrals} \end{array}$$

$$\text{or } \eta' \rightarrow \rho^0 + \gamma, \quad \rho \rightarrow \pi^+ + \pi^-.$$

The name,  $\eta'$ , for this resonance is coming to be preferred over the former name,  $X^0$ , since the probable quantum numbers  $I(J^{PC}) = 0(0^-)$  are the same as those of the  $\eta$ .

A study of the distribution of the normal to the decay plane of the  $\eta \pi^+ \pi^-$  with respect to the beam direction (in the  $\eta'$  rest frame) shows this distribution to be uniform, consistent with the spin-parity assignment  $0^-$ . A rough cross-section determination for  $\eta'$  production in the above reaction as a function of beam momentum indicates that the excitation function rises moderately sharply from the threshold at  $p_{K^-} = 1.64$  BeV/c to a peak of about 140  $\mu\text{b}$  at about 2.1 BeV/c, then falls off quickly to about 70  $\mu\text{b}$  at 2.45 BeV/c, and continues falling off, but very slowly, up to 2.7 BeV/c. The possibility of a  $\Lambda \eta'$  resonance with a mass of about 2300 MeV will be examined. In collaboration with G. R. Kalbfleisch of BNL, a search was made for charge-conjugation-violating decay modes of the  $\eta'$ , including  $\eta e^+ e^-$  and  $\pi^0 e^+ e^-$ ; C-nonconserving asymmetries in the  $\eta \pi^+ \pi^-$  and  $\pi^+ \pi^- \gamma$  modes were also searched for. The results were consistent with conservation of C, although the statistics were insufficient to make a strong statement. (AR)

### $K^-$ Interactions in Deuterium

The deuterium exposure consisted of 150 000 pictures, of which about 3/4 have been scanned. A total of 8500 events of the following topologies have been measured: three or four prongs with no secondary decays, three or four prongs with a secondary decay, and one to four prongs with a V. In  $K^- n$  interactions the initial state has pure isotopic spin 1, thus giving access to the  $I = 3/2$  final state in the  $K \pi$  system and the  $I = 2$  final state in the  $Y \pi$  system. So far the data show no evidence for resonances in these states. The

$\eta'$  (958) has been looked for in the reaction  $K^-n \rightarrow \Lambda\eta'$ . Where seven events would be expected if the  $\eta'$  had  $I = 1$  no events are seen,

thus confirming the assignment  $I = 0$ . (ABG, AR, FS, RDT)

### $\pi$ 63 Experiment

This was an exposure, totaling 30 000 events/mb, of the 72-inch hydrogen bubble chamber to a  $\pi^-$  beam at 14 momenta ranging from 1.6 to 4.2 BeV/c. Some film was taken with deuterium in the chamber. The film was taken between February 1963 and August 1964. A number of results have been published.

#### Branching Ratios for Decays of the $f_0$ , $A_2$ , and $K^*(1400)$ Mesons

Thus far it has been possible to associate the low-mass baryon and meson resonances with SU(3) multiplets. In addition to providing a mass relation for members of a multiplet, the symmetry model relates their partial widths for decay into lower-mass multiplets. With the discovery of the  $f'(1500)$  it appears that the sequence  $f_0(1253)$ ,  $A_2(1320)$ ,  $K^*(1400)$ , and  $f'(1500)$  represents a nonet of  $J^P = 2^+$  mesons. Because of the variety of decay modes accessible to these states, a comparison of available experimental data with the predictions based on SU(3) is of interest. The branching ratios were estimated by comparison of the final states produced in  $\pi^-p$  reactions at 3.2, 3.9, and 4.2 BeV/c. Agreement with theoretical predictions is excellent.<sup>1</sup> (SUC, OID, LMH, RIH, LDJ, JK, DHM)

#### Analysis of $\pi\rho$ Enhancements in $\pi^-d$ Interactions at 3.2 BeV/c

The  $\pi^\pm\rho^0$  enhancement in the interval 1.0 to 1.4 BeV has been shown to consist of two peaks: the  $A_1(1080)$  and the  $A_2(1320)$ . Although the properties of the  $A_2$  peak are well understood, the structure of the  $A_1$  peak remains obscure. No related decays have been established; in addition, possible kinematic origins for the enhancement have been suggested. In the present work, the  $\pi^-\rho^-$  and  $\pi^-\rho^0$  systems were examined under similar kinematic conditions. No significant enhancement is observed in the  $\pi^-\rho^-$  system, precluding the interpretation of either A peak as

an  $I = 2$  resonance. Several features of the data in the  $A_1$  region, when considered as a kinematic effect, are in qualitative agreement with predictions for the mechanism proposed by Deck.<sup>2</sup> In particular, the momentum-transfer dependence in the  $A_1$  region is inconsistent with those observed for known meson systems produced by  $\rho$  exchange.

Approximately 250 events were observed in which the deuteron survived. The events are dominated by the  $\rho^0$  production; in addition, the  $\pi^-d$  effective-mass distribution shows a peak at 2170 MeV, where the  $\pi^-$  can interact strongly with either nucleon in the  $N^3_3$  state. No  $A_2$  production is observed although the  $M(\pi^-\rho^0)$  distribution still peaks in the  $A_1$  region. This lends additional support to the assumption that the  $A_1$  represents kinematic enhancement. (LS, OID, DHM)

#### Production of $\phi$ Mesons in $\pi^-p$ Interactions Around 2.0 BeV/c

In a continuing study of  $\pi^-p$  interactions from 1.6 to 2.22 BeV/c, 76 events of the type  $\pi^-p \rightarrow nK^+K^-$  have been identified. In each event accepted, at least one of the K mesons decays in the bubble chamber. The  $K^+K^-$  effective-mass spectrum shows a seven-standard-deviation enhancement at the mass of the  $\phi$  meson. A preliminary study of the decay angular correlations indicates that the  $\sin^2\theta$  dependence expected for production through  $\rho$  exchange is markedly distorted because of absorptive effects. This is similar to the situation observed in the reaction  $\pi^+d \rightarrow \omega p(p)$ .<sup>3</sup> (RIH, SUC, OID, LMH, JK, DHM)

1. S. L. Glashow and R. H. Socolow, Phys. Rev. Letters 15, 329 (1965).
2. R. T. Deck, Phys. Rev. Letters 13, 169 (1965).
3. H. O. Cohn, W. M. Bugg, and G. T. Condo, Phys. Letters 15, 344 (1965).

### K65 Experiment

This exposure of the 25-inch hydrogen bubble chamber to a  $K^-$  beam with lab momentum 400 MeV/c was begun in early August. About 150 rolls of film with a total of about  $1.5 \times 10^6$  incident  $K^-$  have been taken. The purpose of the experiment is to study in greater detail than hitherto possible the prop-

erties of  $\Sigma$  and  $K^0$  decays. Scanning of the first 100 rolls yielded about 40 000 hyperons and K mesons. Measurements have begun. The new programs SIOUX and ARROW are being used in the data processing. (MHA, ROB, FSC, ABG, LKG, GRL, JJM, FTS, MLS, RDT, ABW)

### P65 Experiment

The exposure of the 72-inch hydrogen bubble chamber to a proton beam with lab momenta of 5.45 and 6.6 BeV/c was begun in mid-August and finished at the first of November. About 450 000 pictures were taken. The experiment is being done in collaboration

with UCLA. First to be examined are reactions in which strange particles are produced. In the following months, in a collaboration with Purdue and Illinois groups, the beam will transport  $\pi$  mesons to the bubble chamber. (GAS, EG, JM, ABW, SGW)

### HIGH ALTITUDE RESEARCH

The feasibility of investigating very-high-energy interactions in a balloon flight experiment has been studied. The information obtainable seems sufficiently attractive to warrant the considerable effort required. The experiment which is supported by NASA, is presently in the advanced design stage and some equipment has already been fabricated.

The physics objectives are (i) to study in detail the nature of primary cosmic rays in the range of 80 to 1000 BeV/c, and (ii) to use these rays to study very-high-energy interactions in the same momentum range. Primary emphasis will have to be restricted to the interactions with larger cross sections to the exclusion of detailed studies of such things as elastic scattering. High-mass particles (of the order of 10 BeV rest mass) will be searched for both in the primary cosmic rays and in the secondary particles resulting from interactions in the balloon experiment payload.

one or more gas Cerenkov counters with a counting threshold around 80 BeV/c for protons, plus a very large superconducting magnet with several large, thin emulsion plates within the magnet structure to detect the curvature of particle orbits passing through the system. In addition, spark chambers triggered by the Cerenkov counters will be used to identify particular tracks in the emulsion (i. e., to distinguish them from background radiation detected by the emulsion). This experimental system is expected to establish the velocity, momentum, charge, sign of charge, position, and orientation of primary cosmic rays passing through the equipment. Depending on flight duration, accepted range of momenta, etc., a single flight should provide about 10 000 such identified particles.

A first engineering flight is planned for late April of 1966 and a physics flight is to follow within a year. (LWA, JAA, RLG, WEH, JBS, DBS, RGS, RRR)

The experimental setup will consist of

### BUBBLE CHAMBER OPERATION AND DEVELOPMENT

Robert D. Watt  
(in charge of Alvarez Group Bubble Chamber Operations)

#### 25-Inch Hydrogen Bubble Chamber

The Trilling-Goldhaber  $K_2^0$  exposure was concluded on May 30 (see Physics Research: Trilling-Goldhaber). About 457 rolls (776 000 pictures) were taken during the run, 257 of them during this report period.

The chamber was then moved to the

Murray K65 beam and the exposure was begun on August 7. On September 30 the chamber was allowed to warm up so that an internal helium leak could be repaired. The chamber was reassembled and ready to operate again on October 19. About 150 rolls of K65 film had been taken by the end of October.

#### 72-Inch Hydrogen Bubble Chamber

The Chinowsky proton experiment had just started at the beginning of the report period. The experiment was concluded on May 30 with a total of 352 rolls of film (235 800 pictures). (See Physics Research: Segrè-Chamberlain).

The Alvarez P65 experiment was begun on August 13 and ended on November 1. A

total of 663 rolls (444 200 pictures) were taken.

Based on the results of model tests, the design has started on the conversion of the 72-inch chamber to an 82-inch bellows expansion chamber. Some components of the expansion system are being fabricated at this date. The new chamber window has been ordered.

DATA REDUCTION OPERATIONS

Edward H. Hoedemaker  
(in charge of the Alvarez Scanning and Measuring Group)

PERSONNEL

From May 1, 1965, to October 31, 1965, the group averaged 78.03 fulltime equivalents. Sick leave, holidays, vacation, etc., make up about 10.2% of these figures; thus the effort was 89.8% of the figures given.

The average effort for this interval was up 12% from the previous six months. This increase was due primarily to the summer help hired under the Youth Opportunity Campaign. Also a rise is usual with the advent of summer, when students work full time.

SCANNING

Film from both the 25-inch and 72-inch hydrogen bubble chambers was scanned according to the following breakdown:

Experiment	Scan and event type	Number of events or rolls
APE	1. Failing events	2770 events
K72	1. Special failing events	800 events
K63	1. Second scan, all event types, 2.55 and 2.70 BeV/c	9700 events
	2. First scan, all event types, 2.1 and 2.67 BeV/c	29800 events
	3. First scan, all event types with vees, 2.1 BeV/c with Pb plate	21600 events
	4. First scan, all event types, 1.7 BeV/c	16000 events
	5. Ambiguities	100 rolls
	6. Check scans, etc.	25 rolls
π63	1. First scan, four prongs (SMP scan and measure)	74 rolls
	2. Conflict scanning	350 rolls
	3. Cross-section scanning	180 rolls
	4. Ambiguities	5000 events

	5. Twice-failing events	4975 events
	6. Zoons	100 events
Spiral Reader	1. First scan, K <sup>-</sup> two prongs, 1.4, 1.5, 1.6, 1.7, 2.1, 2.45, 2.55, 2.63, 2.7 BeV/c	81700 events
	2. First scan, π <sup>-</sup> two prongs 1.5, 1.6, and 2.5 BeV/c	4450 events
K25	1. First scan, all event types	110 rolls
P65	1. First scan, all event types	28000 events

MEASURING

The following gives the production by machine:

	Number of events measured	Number of hours of measuring
Francenstein measuring projector		
MPIIA	18671	2154
MPIIB	19266	2588
MPIIC	18848	2470
MPIID	22534	2725
Total (Francensteins)	79289	9937
SMP measuring projector		
SMP 1	16812	1316
SMP 2	11342	1037
SMP 3	14053	1299
SMP 4	14061	1179
SMP 5	13450	1089
Total (SMP's)	69748	5920
Spiral Reader measuring projector		
SR 1	77180	1363
Grand Total	226187	17220

## DATA REDUCTION DEVELOPMENT

SMP System

Frank Neu, Maurilio Antuna, Jr., Richard W. Casey,  
Ernest Currier, and Alice J. Lee

The SMP system has satisfactorily measured large numbers of events from several 72-inch bubble chamber experiments. There were no major development projects related to the system during the last 6 months. Construction of a sixth SMP was begun. Some minor improvements were made.

A 17-inch cathode-ray tube for visual display of digitized points was installed. Error detection and alarm circuits were added to detect (i) "scalers not working," (ii) "no video signal," and (iii) "digitizer not working." Possible changes of the critical periscope system, including the feasibility of using air bearings, were studied.

For easier and more efficient use by the measurers, tape-handling routines for reading list tapes and writing output tapes were redesigned and rewritten. A track-intersect program was completed. This determines the coordinates of a vertex having more than two charged tracks if a sufficient amount of information is available, or requests a cross measurement if the information is not available. The final vertex point is always tested for consistency with the measured tracks.

Numerous other minor changes of hardware and programs removed inefficiencies and defects.

Spiral Reader System

Lester J. Lloyd, Gerald R. Lynch, James H. Burkhard,  
Jon D. Stedman, Glenn T. Armstrong,  
James N. Baldrige, and Neven D. Travis

In the past 6 months about 80 000 events were measured on the Spiral Reader (see Data Reduction Operations). At the end of this period the average rate of measurement for events with one vertex was about 90 per scheduled hour. A comparison between Spiral Reader and Franckenstein measurements showed no significant difference in the accuracy of the two devices on similar tracks.

A new PDP4 computer program for control of the measurement process is in operation and leads to a significant increase in the measuring rate. The program has been generalized to handle multivertex events. The completion of a system for automatic measurement of fiducial marks makes possible their measurement in 6 seconds per triad rather than the 12 to 15 seconds previously necessary with manual operation. An improved stage servo system has been installed,

giving increased speed and reliability of the stage movement. Improvements in the video and track-detecting electronics have been developed and are being installed. These will improve the time response of the electronics and result in better track ionization data.

POOH, the program that filters the desired event tracks from background, has been modified to handle multivertex events. A study is being made to determine the feasibility of saving events now rejected by the filtering process because of ambiguities (about 10% of the events) by using human intervention on a computer-controlled cathode ray tube. Routines for matching tracks measured in the different views are now usable with either 72-inch or 25-inch bubble chamber film. POOH is being modified to operate on the CDC 6600 computer, when that becomes available.

## PROGRAMMING EFFORT

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

Personnel

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

Benjamin F. Abington II	James H. Burkhard
Margaret H. Alston	Richard W. Casey
Glen T. Armstrong	Lynn J. Champomier
James N. Baldrige	Barbara J. Cottrell
J. Peter Berge	Orin I. Dahl

Cecil T. Draper	Alice J. Lee
Marjorie S. Hutchinson	Thomas H. Oliver
A. David Johnson	Jon D. Stedman
Nancy K. Joseph	Tomas R. Tonisson
Max Leavitt	Neven D. Travis

tion) information from the Spiral Reader.

#### Kinematics Fitting Programs

The program SQUAW for the CDC 6600 has successfully processed events from the 25-inch bubble chamber.

#### Library Programs

Maintenance of LYRIC II was provided as an aid to its users. Several subroutines of LYRIC that were written in assembly language for the IBM 7094 have been written in Fortran IV for the CDC 6600. Many of the LYRIC operations have been verified on the CDC 6600.

#### Introduction

The Alvarez Programming Group spent most of its effort preparing for the CDC 6600 computer. New programs were written and some old programs were transcribed to run under the CDC operating system. Maintenance of existing IBM 7094 and 7044 programs for support of the physics group was given high priority.

#### General Information

The bubble chamber analysis programs that will run on the CDC 6600 computer are SIOUX (made up of two programs, TVGP and SQUAW), ARROW, LYRIC, and SUMX. TVGP is a geometry program that reconstructs a track in space from measurements of the track in two or three views. TVGP replaces the PANG part of the IBM 7094 program called PACKAGE. SQUAW is a program that does multivertex kinematics fitting. It replaces the KICK part of PACKAGE. The combination of TVGP and SQUAW, SIOUX, is analogous to PACKAGE. ARROW is a program for processing SQUAW output through various further calculations. LYRIC is a library program which keeps a history of the processing for each event in an experiment. SUMX is a general data-plotting program.

#### Mass Store

In June the contract for the purchase of a mass storage device from IBM was completed. This device will solve some tape-handling problem in data analysis. The best method for connecting the mass storage device to the CDC 6600 computer and to design the operating system is being studied.

#### Physics Analysis Programs

The program SUMY is now operative on the 7094 and 7044. It is a variation of SUMX that takes control from a calling program instead of from control cards. The CDC 6600 version of SUMX has developed to the point where histograms and ordered lists are made from a tape-simulating program.

#### Scanning and Measuring Projector (SMP) Programs

(See Data Reduction Development.)

#### Spiral Reader Programs

(See Data Reduction Development.)

#### Geometric Track Reconstruction Programs

The program TVGP for the CDC 6600 has successfully processed events from the 72-inch and the 25-inch bubble chambers.

PACKAGE was modified to process additional types of events from the K63 experiment and to accommodate pulse-height (ioniza-

#### Miscellaneous Support Programs

Many programs were written to facilitate the development of the new CDC 6600 computer programs. A general update routine UPDLRL was written to modify Fortran source programs on magnetic tape and thus eliminate handling large decks of cards. WEASEL, a program to calculate optical distortions in the bubble chamber, has been written and is in the initial debugging stage. Programs were written to change formats from the 36-bit word of the IBM 7094 computer to the 60-bit word of the CDC 6600 computer. Some of these will become standard routines that will make it possible to read magnetic tape written on IBM machines into the CDC computer. The rest are special-purpose programs that permit the use of present data for checking the new programs.

PHYSICS RESEARCH

Kenneth M. Crowe in charge

STUDY OF THE THREE-BODY  
LEPTONIC DECAYS OF THE  $K^+$

Kenneth M. Crowe, Michael Zeller,  
and Ned Dairiki

Among the objectives of the present Bevatron experiment is a study of the decay mode  $K_{\mu 3} \rightarrow \pi^0 + \mu^+ + \nu$ . The measurements include muon momentum spectra and the angular distribution of the decaying muon in a spark chamber, as well as spark chamber detection of  $\gamma$  rays from the associated  $\pi^0$  for a fraction of the events. The analysis in this instance will center on the measurements of the  $K_{\mu 3}$  muon polarization, momentum distribution, and relative  $K_{e 3}/K_{\mu 3}$  branching ratio as correlative determinations of the form-factor ratio  $\xi = f_-/f_+$  for the three-body leptonic modes and the universality of the V-A interaction.

The data were taken in a Bevatron run between November 1964 and August 1965. Vidicon digitizing systems were used to read the spark chambers, and an on-line PDP-5 computer stored the events on magnetic tape. The stored information includes counter, wire chambers, particle times of flight, and  $K^+$  lifetime. The writing of the computer programs to read and kinematically analyze the events is under way, and preliminary results are being examined.

Another primary objective of the  $K^+$  experiment is to examine the  $K_{e 3}$  mode of decay. The shape of the electron momentum spectrum and the angular correlation between the electron and  $\pi^0$  were measured and are now being analyzed in order to determine the momentum dependence of the form factor for the strangeness-violating interaction.

The electron events are differentiated from other events by means of a hydrogen Cerenkov counter, placed near the  $K^+$  stopping target, and a water Cerenkov counter near the focal plane of the spectrometer. Wire chambers on the focal plane were used to determine particle momentum. An aluminum-plate spark chamber was used to determine particle ranges. A brass-plate spark chamber around the  $K^+$  stopping target was used to detect  $\gamma$  rays from  $\pi^0$  decays.

The results of the experiment are presently being analyzed by use of a combination of hand scanning and computer analysis. An analysis of a small sample of events indicates that a total of approximately 4000  $K_{e 3}$

events can be expected, 2500 of which fall in the region of the wire chambers. Reduction of the data for a number of  $K_{\mu 2}$  events shows a momentum resolution of  $\pm 3\%$  for those events which fall on the wire chambers. The other 1500 events fall into three counters representing a momentum spread of approximately 15% each.

The programs for the analysis of the bulk of the events are being completed and the analysis will continue.

$\pi$ - $\pi$  INTERACTION

Kenneth M. Crowe, Ned Dairiki,  
and Tin Maung

Data analysis of our last run on  $\pi^- + p \rightarrow \pi^0 + \pi^0 + n$  has been completed. Using the S-dominant solution of the  $\pi$ - $\pi$  effective range equation of Chew and Mandelstam, we can obtain a lower limit for  $I = 0$   $\pi$ - $\pi$  S-wave scattering length of 0.65 pion Compton wavelength with a 90% confidence level. The analysis using Chew-Low extrapolation method gives a  $\pi^+ + \pi^- \rightarrow \pi^0 + \pi^0$  cross section of 60 mb or larger. The experiment, with analysis and results, has been described in a paper submitted to Physical Review Letters (Tin Maung, K. M. Crowe, and N. T. Dairiki, Experimental Study of the  $\pi\pi$  Interaction in the Reaction  $\pi^- + p \rightarrow \pi^0 + \pi^0 + n$  at Incident  $\pi^-$  Energy of 378 MeV, UCRL-16444, Nov. 1965).

Detail design and fabrication of equipment are now in progress for a comprehensive run tentatively scheduled for June 1966.

$\pi$ -MESIC x RAYS

David Jenkins, Frank Cooley,  
and Peter Lindstrom

We are now analyzing data obtained in July during an experiment on the 184-inch Cyclotron.  $\pi$ -Mesic x-ray spectra were obtained for 70 elements with Z (atomic number) ranging from Z = 3 (lithium) to Z = 92 (uranium). The x rays were measured with a lithium-drifted germanium detector of about 3 keV resolution, and we observed the energy, intensity, and width of the x-ray lines.

On analyzing our data, we have looked for shifts in the energy levels from that predicted by the Klein-Gordon equation, and we have found large variations due to the strong interaction between the pion and the nucleus.

As we go up in  $Z$ , the radius of the nucleus becomes larger, and nuclear absorption increases because there is a greater chance of finding the pion in the nucleus. For  $Z = 5$  the rate of nuclear absorption begins to compete with the  $2p \rightarrow 1s$  radiative transition rate, and the x rays begin to disappear. When  $Z = 23$ , nuclear absorption competes with the  $3d \rightarrow 2p$  transition, for  $Z = 54$  it competes with the  $4f \rightarrow 3d$  transition, and for  $Z = 92$  it begins to compete with the  $5g \rightarrow 4f$  transition.

Two things happen when nuclear absorption becomes important. There is a shift in the x-ray energy, and the x-ray line is broadened because of an uncertainty in the energy level. Both these effects can be related to the pion-nucleon scattering amplitudes.

We also observe large shifts (a few keV) due to vacuum polarization.

All these effects will be investigated in more detail during a new experiment which is planned for January.

#### THE PION MASS MEASUREMENT

Robert E. Shafer

The previously reported bent-crystal measurement of the  $\pi^-$  mass<sup>1</sup> is being written up in detail as a thesis. Two publications, based on the thesis, are in the process of being completed. One discusses the construc-

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1. R. E. Shafer, K. M. Crowe, and D. A. Jenkins, Phys. Rev. Letters 14, 923 (1965).

tion and operation of the bent crystal spectrometer, and the other is a detailed analysis of the pion mass measurement.

#### PION FORM FACTOR

Kenneth M. Crowe and J. Miller

An experiment is being planned to determine the pion form factor by a method described by Hofstadter and Sternheim [Nuovo Cimento 38, 1954 (1965)].

The method involves the scattering of  $\pi^+$  and  $\pi^-$  mesons from helium in the region of the minimum at 70 deg scattering angle. At this point the analysis indicates that the Coulomb interference terms will change sign and the magnitude of the difference between  $\pi^+$  and  $\pi^-$  cross sections will be modified by finite size of both the helium and pion. Effects of order 5% are predicted for pion radius approximately 1.5 fermi. The experiment is being instrumented for the 184-inch cyclotron, to be begun in January 1966.

#### THE $\mu$ -DECAY SPECTRUM IN COPPER

Philip Beilin

The free- and bound-muon decay spectra in copper have been compared with the theoretical predictions of both Michel and Huff. In order to compare the theoretical predictions with the experimental results the sensitivity of the results to uncertainties in the calculated energy loss process is being studied. The results will be prepared for publication.

PHYSICS RESEARCH

Harry H. Heckman in charge

## NUCLEAR EMULSION GROUP

Particle ResearchBRANCHING RATIOS IN  $K^+$  MESON DECAY

Poh-shien Young

This experiment has been completed. To carry out the study of the branching ratios in  $K^+$  decay, a beam of  $10^6$   $K^+$  mesons was brought to rest in a volume of  $14 \text{ cm}^3$  within a nuclear emulsion stack. The stack was sufficiently large to bring to rest  $K^+$  secondaries of the longest range, provided their directions of emission were within certain selected cones. Some 700  $K^+$  decays were chosen as the sample for the experiment. The principal method for identifying the secondaries was following the tracks to rest. Ionization measurements were used to resolve ambiguities. The branching ratios found in this experiment are:

<u>Decay Mode</u>	<u>Ratio (percent)</u>
$K_{\mu 2}$	$61.8 \pm 2.9$
$K_{\mu 3}$	$5.4 \pm 0.9$
$K_{\pi 2}$	$19.3 \pm 1.6$
$\tau$	$6.0 \pm 0.4$
$\tau'$	$2.3 \pm 0.6$
$K_{e 3}$	$5.3 \pm 0.9$

These results will appear in a thesis to be submitted in partial fulfillment for the Ph. D. degree, UCRL-16362.

Space ResearchTRAPPED PROTONS IN  
SOUTH ATLANTIC ANOMALY

Harry H. Heckman

Emulsion packages from polar-orbiting satellites were successfully recovered on two occasions during the period May-Oct. 1965. This brings to 25 the number of emulsion recoveries since September 1962. The analysis of these emulsions is in progress and is part of a continuing program to study the temporal variations in the trapped radiation during the solar cycle period. The most significant variation in the flux of 65-MeV protons we have observed to date occurred in June 1965 (our latest flight), in which the flux is approximately twice the 1963-4 average. No change in the east-west asymmetry of the proton flux was observed, however. Such changes in the inner-zone protons at low altitudes are to be expected. For example, the calculations by R. C. Blanchard and W. H. Hess (NASA X-640-64-50, 1964) predict a monotonic increase in the flux of 65-MeV protons by a factor of about two during the same period be-

cause of solar-cycle changes in atmospheric density.

## ENVIRONMENTAL EMULSION TESTS

John N. Dyer and Harry H. Heckman

In preparation for scheduled emulsion experiments aboard earth-orbital Apollo missions, we have begun a technical program to study the properties of Ilford emulsions, types G and K, in extreme, spacelike environments. Upon subjecting desiccated emulsions to temperatures from  $-25^\circ$  to  $+125^\circ$  C for a 24-hour period, we have observed a moderate increase in the density of fog grains until critical temperatures of  $65^\circ$  C for K emulsion and  $75^\circ$  C for G emulsion are reached. Above these temperatures, fogging rapidly increases and the emulsions become opaque approximately  $15^\circ$  C above the critical temperatures. We are examining the time dependence of fog density in emulsion maintained at  $50^\circ$  C for up to 24 days. In general, we find fog grain density higher in K than in G emulsions by a factor of at least 2 at all temperatures investigated.

THEORETICAL DIVISION

David L. Judd in charge

SCATTERING THEORY

In S-matrix theory the notions of space and time do not enter as primary concepts. This raises the question of understanding the causal aspects of nature. A condition of macroscopic causality has been formulated within the S-matrix framework. It says, roughly, that if the initial- and final-particle free-wave packets do not intersect appreciably before or after a spacelike surface  $\sigma$ , respectively, then there is no appreciable transition probability. The condition is justified by semiclassical arguments. The causality condition is shown to imply that, aside from an infinitely differentiable term, the scattering function is analytic in the neighborhood of all physical-region Landau singularities. The rule for continuing past all such singularities is deduced. From a somewhat stronger macroscopic causality condition it is shown that the only possible singularities in the physical region are the Landau singularities that occur in perturbation theory. (Colston Chandler and Henry P. Stapp)

A previously given S-matrix proof of the normal connection between spin and statistics depended on the assumption that the magnitudes of self-conjugate combinations of particle-antiparticle amplitudes were observable. This assumption has no experimental basis for charged particles. A new proof has been obtained that does not depend on this assumption. It is based on the pole factorization theorem and the Hermitian analyticity property of the scattering functions. (Henry P. Stapp)

A fundamental problem in extending S-matrix methods to many-particle problems is to obtain the discontinuity equations for all cuts that enter the physical region. Certain conjectures have been made and their consistency checked in a variety of special cases. Work is progressing on a general derivation of these equations. (Joseph Coster and Henry P. Stapp)

An attempt is being made to generalize treatments of the complex angular-momentum plane to include three-body intermediate states. Previous proofs of meromorphy have considered only two-body intermediate states. The method of treatment which has been adopted is based on an extension of previous work on three-body N/D equations to include complex angular momenta. The extension is not quite straightforward, but some of the problems have been dealt with and it appears

that the remainder can be solved. It is reasonable to hope that one can prove that the scattering amplitude is analytic in the angular-momentum plane except for the expected cuts and poles. Some properties of the Regge trajectories should also be obtained as a result of this work. (Stanley Mandelstam)

Application of the quantum theory of measurement to the observations relating to unstable particle decay has been studied. The finite duration in time of an observation is required to resolve ambiguities in the decay law. (M. L. Goldberger, Princeton University, and K. M. Watson)

An explicit integral representation is derived for the determinant of the D matrix for the multichannel scattering problem, in terms of the physical eigenphase shifts. This representation is used to prove Levinson's theorem in the multichannel case. A similar representation is derived for a generalized D function for many-body scattering, and in general for any number of channels with any number of particles in them. The problem of disconnected parts of the many-body S matrix is overcome by factorizing the S matrix into a product of connected operators. The N/D equations, given by Mandelstam, for three-body scattering, are used in the fixed Dalitz-region approximation, where they are easily generalized to the multichannel, many-body case. Levinson's theorem is extended, with the usual assumptions as to the asymptotic behavior of the left-hand cut, to the most general case.<sup>1</sup> (David J. Gross)

The technique used by Faddeev to obtain connected equations for the nonrelativistic three-body T matrix is generalized for four particles. It is shown that the four-body equations are completely determined by the solutions for all the possible two-body subsystems, as is the case in the three-body problem. This approach can be extended to more complicated multiparticle systems. (Victor Alessandrini)

The off-energy-shell behavior of two-particle scattering amplitudes and possible factorizable approximations to the off-energy-shell, two-particle scattering amplitude,

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1. David J. Gross, Many-Body D Function and Levinson's Theorem (to be submitted for publication).

which are useful in multiparticle scattering calculations, are being studied. Particular attention is being paid to a new approach to two-particle scattering based on a nonsingular integral equation that was recently formulated by Noyes.<sup>2</sup> (Thomas R. Mongan)

Development of practical methods for carrying out dynamical calculations in strong interaction physics via the Bethe-Salpeter equation was continued, and properties of the equation relating to unitarity, both elastic and inelastic, to bound states in coupled channels, and to partial-wave decompositions, both three- and four-dimensional, were obtained. The theoretical groundwork necessary to a numerical calculation of spin 0 plus spin 1/2 scattering was set up. (Charles Schwartz and A. Charles Zemach)

The connection between Regge poles and elementary particle poles is being explored. If, in a field theory,  $Z_3 \rightarrow 0$  and  $\Gamma(s)$  (proper vertex function)  $\rightarrow 0$  so that  $Z_3/\Gamma(s) \rightarrow 0$ , then the elementary particle becomes dynamical in the Regge sense. The bootstrap equation is automatically derived under these conditions. Our analysis is restricted by the assumption of two-particle multichannel unitarity, but is otherwise general. A previous work<sup>3</sup> is also being re-examined under these conditions. (Takesi Saito, formerly Takesi Ogimoto)

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2. H. Pierre Noyes, Phys. Rev. Letters 15, 538 (1965).

The high energy behavior of scattering amplitudes is being investigated on the basis of the analyticity and unitarity of the S matrix. Attention is also being paid to the possible existence of cuts in the complex angular momentum plane and their effect on the scattering amplitude. (Chung-I Tan)

The Regge analysis shows that, for large (unphysical) values of the cosine of the angle of scattering, a scattering amplitude varies as this cosine raised to a power which depends on the energy. A study has been aimed toward finding this result without resorting to a partial-wave analysis and the Sommerfeld-Watson transformation, but so far it has not met with success. It is felt that a direct solution of the problem might give valuable insight into the nature of the three-body problem. In connection with the study of the aforementioned problem an alternative method of solution of the problem of radio wave propagation was found. This method, as well as the original solution based on the Sommerfeld-Watson transformation, is due to Sommerfeld. The method involves an unusual theory of complex eigenvalues. An attempt is being made to extend this method to problems arising from the Schrödinger equation. (Joseph V. Lepore and Robert J. Riddell, Jr.)

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3. Takesi Saito, Unsubtracted Dispersion Relations in Weak Interactions and a Partially Conserved Axial-Vector Current, in Conference on Resonant Particles, 1965 (Ohio University), and Phys. Rev. (to be published).

## DYNAMICAL CALCULATIONS AND SYMMETRY STUDIES IN STRONG-INTERACTION PARTICLE PHYSICS

The contribution of the P (Pomeranchuk) and P' trajectories to the generalized two-particle potential was shown to be repulsive and effectively of long range.<sup>4</sup> A rough expression for the P potential was derived in terms of the high-energy total cross section and associated diffraction peak. This potential was shown to be capable of an important narrowing effect on resonance widths. (G. F. Chew)

The  $d_{3/2}$  meson-baryon resonances have been investigated on the basis of a multichannel Bethe-Salpeter equation in the unitary symmetry limit. The force mechanism studied consists of a box diagram which provides strongly attractive d-state forces corresponding to the octet channels. A reduction of the

Bethe-Salpeter equation to a single-dimensional relativistic integral equation which incorporates two-body unitarity has been effected along the lines of Blankenbecler and Sugar's method. The equation was solved by the determinantal method to lowest order. The model accounts for a singlet and an octet of  $d_{3/2}$  meson-baryon composite states. A report has been prepared [Dynamics of a Singlet and Octet of  $d_{3/3}$  Meson-Baryon Composite States (Ph.D. Thesis), UCRL-16366, Aug. 1965]. (P. van der Merwe)

We have studied  $\pi N$  scattering in the  $P_{11}$  state in an attempt to understand the dynamical origins of the large phase shift and to see how it relates to the nucleon itself. Since one-channel calculations give a negative phase shift, we feel that it is a phenomenon largely associated with inelastic channels, and that  $\pi\Delta$  is the most likely candidate. A resonance of the  $\pi\Delta$  channel would need to be included as a CDD pole in a one-channel  $\pi N$

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4. Geoffrey F. Chew, Pomeranchuk Repulsion and Resonance Narrowing (UCRL-16245, June 1965) Phys. Rev. (to be published).

calculation. In this way good fits to the phase shift would be obtained and yet the nucleon would emerge in almost the same position as if the CDD pole were neglected. Further calculations are being performed to support some of these statements. (John Schwarz)

A study has been made of the effects of baryon Regge trajectories in crossed reactions on high-energy backward  $\pi^{\pm}p$  scattering. Two general features have been investigated, namely peak shrinkage and polarization. The work on peak shrinkage was carried out in collaboration with Professor Geoffrey Chew. The conclusion reached was that because of the large slopes of the baryon trajectories, the peak shrinkage in these reactions should be considerably more prominent than that seen in forward scattering. In the work on polarization, it was found that because the baryon trajectories in the crossed channel are associated with fermions, the polarization of the recoil proton should be large and positive for  $\pi^{-}p$  and large and negative for  $\pi^{+}p$ . (John D. Stack)

A Regge-pole analysis was begun of backward  $\pi^{\pm}p$  scattering at high energy.<sup>5</sup> The required N and  $\Delta$  trajectories appear reasonable in slope and curvature, as do the associated residue functions. Predictions concerning peak shrinkage and polarization will be possible. (F. Arbab of the Mathematics and Computing Services, G. F. Chew, and John Stack)

A calculation of the elastic phase shifts for pion-nucleon scattering using the Bethe-Salpeter equation in the ladder approximation is in progress. The Wick rotation was found to be possible for a total energy below the first inelastic threshold. A variational principle for the phase shifts has been formulated. The calculation follows closely the one presented in a paper by Zemach and Schwartz.<sup>6</sup> (Klaus D. Rothe)

The calculation of the symmetric scattering length in  $\pi N$  scattering done by Igi<sup>7</sup> several years ago, using forward dispersion relations and Regge asymptotic behavior, has been reconsidered in the light of new experimental data on  $\pi N$  total cross sections. The

results give a value of the  $P'$  intercept at  $t = 0$  of  $0.69 \pm 0.01$  with no indication of any Regge cuts appearing asymptotically. The extra constraint on the Regge parameters provided by the Igi sum rule<sup>7</sup> and the experimental value of the scattering length was incorporated into the Rarita-Phillips fitting program<sup>8</sup> and a  $\chi^2$  value was obtained which was better than the  $\chi^2$  values of their four fits. This indicates that the intercept  $\alpha_{P'}(0)$  can be large ( $> 0.5$ ) without disrupting fits to high energy  $\pi N$  data. (Joseph Scanio)

The new form of the strip approximation devised by Chew<sup>9</sup> has been applied to the problem of "bootstrapping" trajectories in the  $\pi$  system. Earlier work with Teplitz on a self-consistent  $\rho$  trajectory<sup>10</sup> has been extended, and a pair of mutually self-consistent  $\rho$  and  $P$  trajectories obtained. These trajectories are rather unlike the physical trajectories, however, and do not preserve unitarity in the asymptotic region. It has been concluded that the new form of the strip approximation is inadequate in that the "potential" is included only in the first Born approximation.<sup>11</sup> (P. D. B. Collins, D. S. I. R. Research Fellow)

The S-wave  $\pi\pi$  scattering amplitude has been examined following the method of Chew and Mandelstam,<sup>12</sup> but including forces from the exchange of  $\rho$ ,  $P$ , and  $P'$  trajectories, as well as a self-consistent S wave. The results depend upon the assumption made about the S-wave scattering length, but it is concluded that a scattering length of 1.0 gives results in the best agreement with experiment.<sup>13</sup> (P. D. B. Collins)

Relativistic three-pion systems have been studied on the basis of the equations proposed by Alessandrini and Omnes.<sup>14</sup> An explicit angular momentum decomposition,

5. Geoffrey F. Chew and John D. Stack, Backward  $\pi^{-}p$  Scattering as a Further Test for Regge High-Energy Behavior, UCRL-16293, July 1965.

6. C. Schwartz and C. Zemach, Theory and Calculation of Scattering with the Bethe-Salpeter Equation, Phys. Rev. (to be published).

7. K. Igi, Phys. Rev. 130, 820 (1963); Phys. Rev. Letters 9, 76 (1962).

8. R. J. N. Phillips and W. Rarita, Phys. Rev. 139, B1336 (1965).

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

10. P. D. B. Collins and Vigdor L. Teplitz, A Self-Consistent  $\rho$  Trajectory in the New Form of the Strip Approximation, UCRL-16112, May 1965.

11. P. D. B. Collins, The Inadequacy of the New Form of the Strip Approximation for the  $\pi$ - $\pi$  Scattering Amplitude (UCRL-16347, Aug. 1965), submitted to Phys. Rev.

12. G. F. Chew and S. Mandelstam, Phys. Rev. 119, 467 (1960).

13. P. D. B. Collins, The S-Wave  $\pi$ - $\pi$  Scattering Amplitudes in the Form of the Strip Approximation (UCRL-16339, Aug. 1965), submitted to Phys. Rev.

14. V. A. Alessandrini and R. L. Omnes, Phys. Rev. 139, B167 (1965).

following the method of Omnes,<sup>15</sup> was given. Suitable approximations for the relativistic off-shell two-body amplitude were examined, and a separable form was used to reduce the equations to their final form. The calculation of the  $I = 0$ ,  $J^P = 1^-$  channel was done on the assumption that the two-body amplitude is well represented by the  $\rho$ . Particular choices for the resonance form factors appearing in the equations were discussed. The behavior of the eigenvalues of the Faddeev kernel was exhibited, and it was explained why the  $\omega$  meson does not appear in such a model. A resonance was found at relatively high energy which does not depend on the choice of the form factors, and seems to correspond to the experimental  $E$  meson. The other three-pion channels were also investigated in all parity and isospin states and with total angular momentum  $J < 3$ . The only part of the two-body amplitude taken into account was the  $\rho$  resonance. The results did not suggest the dynamical origin of the  $A_2$ , and many isoscalar resonances were found in a small energy region.<sup>16</sup> (Jean-Louis Basdevant, CNRS, Paris, France, and NATO fellow, and Rodney E. Kreps, Physics Department, University of California, Berkeley)

Calculations of the  $\pi\pi$  amplitude in the multichannel strip approximation are being carried out with use of Reggeized potentials. The channels included the  $\pi\pi \rightarrow \pi\pi$ ,  $K\bar{K} \rightarrow K\bar{K}$  with the potentials due to the exchange of  $\rho$  and  $P$ , and  $\pi\pi \rightarrow K\bar{K}$  with the potential due to the exchange of  $K^*$ . Preliminary results seem to indicate that the additional channels do not have much effect on the  $\pi\pi$  amplitude. (N. Bali, Consejo Nacional de Investigaciones Científicas y Técnicas fellow, Argentina, and Shu-yuan Chu)

An investigation of the properties of partial-wave scattering amplitudes for multichannel problems has been continued.<sup>17</sup> Also, a model for the  $\pi\pi$  scattering amplitude is being constructed by extending a method suggested by Balazs.<sup>18</sup> (Jerome Finkelstein)

The  $I = 0$ ,  $\pi\pi$  scattering length has been evaluated using a forward direction elastic-scattering dispersion relation. The high-energy contribution to the dispersion integral has been obtained with an assumption that the

high-energy behavior of the forward scattering amplitude is dominated by a few leading crossed-channel Regge poles, while any available experimental information on total  $\pi\pi$  cross section has been used to compute the low-energy contribution. The scattering length was found to be negative, with a calculated value of  $-1.7^{+1.3}_{-0.5}$  (in pion-Compton wave lengths). Evaluation of the  $I = 1$  amplitude at threshold yielded the value  $-0.4$ , which was found to be consistent with zero; this indicated that the method used in evaluating the scattering length was not unreasonable.<sup>19</sup> (Heinz J. Rothe)

Presently an investigation is under way to establish the connection between the absorption model of Gottfried and Jackson and the Regge pole model; particular attention is given to a possible connection between the absorptive corrections and cuts in the complex angular momentum plane of the analytically continued partial-wave amplitude. (Heinz J. Rothe)

The calculation of the slope of the Regge trajectory near the  $\Delta$  particle has been completed. Its value turned out to be half of what one would expect on experimental grounds. In the same model, the calculated zero momentum transfer intercept is approximately  $+0.3$  instead of  $-0.3$  found by Chew and Stack,<sup>20</sup> whereas the shape as well as the curvature of the trajectory is roughly reproduced. A new approach based on Balazs's techniques to deal with the far away left-hand cut is being studied. (Andres A. Garcia, fellow of A. I. D. and Comisión Nacional de Energía Atómica, Argentina)

The crossing relations for nucleon-nucleon scattering have been studied, and a new set of crossed-channel amplitudes has been found for which the direct-channel experimental quantities have a very simple form. The differential cross section, depolarization, correlation, polarization, and rotation parameters are studied in this formalism. By applying the results to the Regge pole model, the Regge parameterization of all the above experimental quantities has been found. Restrictive tests of the Regge pole hypothesis are derived from the factorization property of the partial-wave spin transition amplitudes. (Richard C. Slansky)

15. R. L. Omnes, Phys. Rev. 134, B1358 (1964).

16. Jean-Louis Basdevant and Rodney E. Kreps, Relativistic Three-Pion Calculation, Part I, UCRL-16233, June 1965; Part III, UCRL-16334, Aug. 1965.

17. J. Finkelstein, Nuovo Cimento 38, 659 (1965); Phys. Rev. 140, B175 (1965).

18. Louis A. P. Balazs, Phys. Rev. 137,

B1510 (1965).

19. Heinz J. Rothe, Evaluation of the  $I = 0$  Pion-Pion Scattering Length Using a Forward Scattering Dispersion Relation, UCRL-16234, July 1965 (submitted to Phys. Rev.).

20. Geoffrey F. Chew and John D. Stack, Backward  $\pi^-p$  Scattering as a Further Test for Regge High-Energy Behavior, UCRL-16292, July 1965.

The crossover of the differential cross section for  $p\bar{p}$  and  $pp$  scattering at high energies has suggested that if one considers only  $f^0$ ,  $f^0'$ , and  $\omega$  Regge poles in the crossed channel, the residue function of  $pp\omega$  needs to vanish at the crossover point. Motivated by this phenomenon, we have started a numerical study of the possibility of such a zero in the residue function in the potential theory by using a potential of the form of

$$-g_A \exp(-m_A r)/r + g_R \exp(-m_R r)/r,$$

with  $g_R > g_A$  and  $m_R > m_A$ . If the zero exists, we will study its dependence on  $g_A$  and  $g_R$ . Work is still in progress. (Ling-Lie Wang)

The investigation of the bounds on the correction to the Born term for a generalized dispersion model<sup>21</sup> has been completed. The bounds were given as functions of the moments of the imaginary part of the partial-wave amplitude. The generalized model was shown to include as special cases the Chew-Arndt, MacGregor-Arndt ( $j_0$  even), Scotti-Wong, and Kantor nucleon-nucleon models. (Judith Binstock)

The numerical calculations of the scattering amplitude for nucleon Compton scattering have been completed. The final analysis of the results is, however, still in progress. It is hoped to derive information on the  $\pi\pi$  S-wave interaction. (Elliot Leader)

A survey of the present phenomenological status of the Regge pole theory of high-energy scattering was carried out, and presented at the 1965 Seminar on Unified Theories of Elementary Particles, in Munich. (Elliot Leader)

A simple treatment of the propagation of  $K_1^0$  and  $K_2^0$  beams through a series of plates was prepared for the benefit of experimentalists involved in the study of CP violation in  $K^0$  decays. (Elliot Leader)

Existence of a unique solution to the multichannel N/D equations in the new strip approximation has been proved from maximum analyticity of the second degree. Calculations have been made for  $\rho$ -meson parameters in coupled  $\pi\pi$  and  $K\bar{K}$  channels with elementary  $\rho$  and  $K^*$  exchange in the crossed channels as input. (Shu-yuan Chu)

21. Judith Binstock, Bounds for the Correction to the Born Term and Application to p-p Scattering for a Generalized Dispersion Model (UCRL-16174, June 1965), Ann. Phys. (N. Y.) (to be published).

The reaction  $\pi^+d \rightarrow pp$  is being considered in the framework of Regge theory by assuming the neutron to be the dominating pole in the crossed channel. The crossing matrix for the helicity amplitudes between direct and crossed channels has been worked out. This study is still in progress. (Huan Lee)

The pseudoscalar meson octet and vector meson nonet have been studied in the context of SU(6). All the meson couplings are P wave except the three-vector coupling, which has in addition an F-wave part. In the approximation that the F-wave contribution is not important, the forces for the scattering of mesons have the same threshold behavior. It was found that the forces were similar enough to match them all at threshold to the same function. A necessary condition for a higher symmetry is then imposed on the coupling constants. It is not clear yet whether the equations have a solution, though work is still in progress. (Richard Haymaker)

In collaboration with Professor S. Fubini, of the University of Turin, Italy, and Professor J. D. Walecka, of Stanford University, work is in progress to study by means of a dispersive technique the algebra of current commutation relations. A particular study has been made of the situation in which the charges are vectors and pseudovectors rather than scalars and pseudoscalars; by assuming a knowledge of the algebra's commutation relations, sum rules involving the magnetic coupling of vector mesons to nucleons and vector meson-nucleon scattering have been obtained. (Gino Segrè)

Approximation methods involving algebras of current operators have recently been employed to obtain results characteristic of higher symmetries of strong interactions. A relativistic field-theoretical formulation of these methods has been developed, and a preliminary application has been made to the evaluation of the D/F ratio of the meson-baryon coupling. A note on this work entitled "Remarks on the Saturation of Equal Time Commutators and Physical Sum Rules" has been submitted to Physics Letters. (Victor A. Alessandrini, Fellow of the C. N. I. y T. of Argentina, M. A. B. Beg, and Lowell S. Brown)

Some calculations have been made in the area of fundamental particle symmetries related to the inclusion of the Poincaré group. We have been oriented toward ways of getting around the beautiful but negative theorem of O'Raifeartaigh,<sup>22</sup> which states that there can

22. L. O'Raifeartaigh, Phys. Rev. Letters 14, 332, 575 (1965).

be no mass splitting under a much broader set of conditions than those discussed by McGlinn, Michel, etc.<sup>23,24</sup> Our hope had been that the work of Ottoson, Kihlberg, and Nilson on minimal coupling might bypass the O'Raifeartaigh conditions in a physically

23. W. D. McGlinn, Phys. Rev. Letters 12, 467 (1964).

24. L. Michel, Phys. Rev. 137, B405 (1965).

meaningful way.<sup>25</sup> In the process we have noted a fundamental error in a recent Russian preprint on the same subject by Kolomytsev and Fakirov.<sup>26</sup> (Owen Fleischman)

25. Ulf Ottoson, Arne Kihlberg, and Jan Nilson, Phys. Rev. 137, B658 (1964).

26. Kolomytsev and Fakirov, preprint, Joint Institute for Nuclear Research, Dubna (1965), p. 2107.

## PLASMA PHYSICS

An analysis of intensity correlation techniques applicable to spectroscopic diagnostics for a plasma has been completed and submitted for publication.<sup>27</sup> The techniques considered include fast electronic autocorrelation observations and the use of tuned circuits (wave guides) to study difference frequencies. (M. L. Goldberger, Princeton University, H. W. Lewis, University of California, Santa Barbara, and Kenneth M. Watson)

The temperature Green's function technique has been employed to calculate the amplitude and intensity correlation functions for the photons emitted from a model source. These correlation functions are expressed in terms of the two- and four-current correlation functions, which may be obtained from the temperature-ordered two- and four-current Green's function by straightforward diagram technique and analytic continuation. Collision broadening and narrowing may be derived. The limitation of the method was discussed. (Shang-keng Ma)

An alternative to open diagram techniques has been employed to obtain a rigorous formulation for the calculation of quenching rates of resonantly excited atoms. The straightforward use of open diagrams results in ambiguities whenever line broadening effects become important. For the sake of simple interpretation it was necessary to limit consideration of atoms for which broadening interactions in the lower state are unimportant. In this case it appears as if the terms figuring into the quenching rate may be directly related to experimentally measured quantities. (Bandel Bezzerides)

A study has been made of the spatial response of an electron plasma to a low-fre-

27. M. L. Goldberger, H. W. Lewis, and K. M. Watson, Intensity Correlation Spectroscopy (UCRL-16397, Aug. 1965), submitted to Phys. Letters.

quency localized electric field,<sup>28</sup> taking into account electron-ion and electron-electron collisions. Expressions were obtained for the response in the kinetic and in the hydrodynamic regimes, and for fully ionized and weakly ionized plasmas. Experimental verification is being planned by A. Wong at UCLA. (Allan Kaufman)

The general area of plasma turbulence has been surveyed. Effort has been made to understand the possible mechanisms for anomalous diffusion of plasma across the magnetic field and in the reduction of the kinetic equations of magnetized plasma<sup>29</sup> so that they can be applied to the study of ion-cyclotron instability.<sup>30</sup> (C. S. Liu)

The use of the temperature Bethe-Salpeter equation in transport theory has been studied, and the equation has been used to derive a convergent kinetic equation for a classical plasma. In the near future the kinetic equation will be used to calculate the conductivity of a classical plasma without the use of an ad hoc cutoff. (Harvey Gould)

A kinetic equation has been obtained for a homogeneous field-free plasma. This equation, which is a generalization of the Lenard-Balescu equation, is valid for both stable and unstable plasmas, and is free from difficulties at a point of marginal stability. It satisfies the conservation laws and leads to an H theorem. Balescu's equation<sup>31</sup> for an unstable plasma contains mathematical errors

28. Burton D. Fried, Allan N. Kaufman, and David L. Sachs, Low-Frequency Spatial Response of a Collisional Electron Plasma (UCRL-16374, Aug. 1965), submitted to Phys. Fluids.

29. N. Rostocker, Phys. Fluids 3, 922 (1960).

30. W. Drummond and M. Rosenbluth, Phys. Fluids 5, 1507 (1962).

31. R. Balescu, Statistical Mechanics of Charged Particles (Interscience Publishers, New York, 1963), p. 441.

and omits a large number of terms without justification. An improved quasi-linear equation was obtained which includes the effect of damped modes as well as growing modes. All terms of the equation are mathematically well-defined, and the equation may be applied to three-dimensional systems. Collision

terms valid to order  $1/\ln\Lambda$  have been obtained for small-amplitude waves in a uniform plasma. This result generalizes the ordinary Fokker-Planck equation from the domain

$$0 \leq \omega \ll \omega_p, \quad 0 \leq k \ll k_d$$

$$0 \leq \omega \ll \Lambda\omega_p, \quad 0 \leq k \lesssim k_d. \quad (\text{John C. Price})$$

#### PHYSICS OF THE NUCLEUS

An investigation has been started into the causes and implications of the so-called Wigner symmetry term in the nuclear binding energy. It is thought to be due to the particularly close matching of the neutron and proton wave functions for nuclei with  $N = Z$ . A model calculation using a potential well in the form of a parallelepiped and a  $\delta$  interaction between the particles is under way. (Wladyslaw J. Swiatecki and Chin-Fu Tsang)

has been completed<sup>32</sup> and submitted to Nuclear Physics. An investigation has been started into the effect of curvature on the surface-energy contribution to nuclear binding energies. Simple model calculations are being performed which show the origin of this and other corrections to the liquid-drop model of the nucleus. (William D. Myers and Wladyslaw J. Swiatecki)

The work on nuclear masses and deformations, which includes a simple description of shell effects and their shape dependence,

32. William D. Myers and Wladyslaw J. Swiatecki, Nuclear Masses and Deformations, UCRL-11980, March 1965.

#### MANY-BODY PROBLEMS

The Proceedings of the Sussex Symposium on Quantum Fluids--which will appear in the January 1966 issue of the Review of Modern Physics--will constitute approximately 150 printed pages. The writing of the discussion sections and general editing was done by a team of about six scientists (of which the author was one), during a 3-week period. (A. M. Sessler)

The effect of size and shape on a degenerate boson system is being investigated. Straightforward application of the Ginzburg-Pitaevskii theory to films and to pores produced results on the onset-of-superflow which correlated well with experimental data. An exact analysis of the ideal Bose gas confined to an arbitrary box demonstrated the marked effect of size upon the thermodynamics at low temperatures; e. g., in a film, the specific heat at constant volume is proportional to the temperature. (V. K. Wong)

The problem of a slow conduction electron in a polar crystal (polaron), in the approximation described by the usual Frohlich Hamiltonian, is being investigated numerically. Work completed so far shows qualitative agreement with previously published results. The

technique is essentially a straightforward, but large-scale, systematic variational calculation. It is expected that this approach will provide accurate values for the ground-state energy and the effective mass,  $m^*$ , of the polaron for a wide range in the coupling constant, including the physically interesting "intermediate coupling" and strong-coupling regions. The polaron has been advantageously studied as a testing ground for various analytical and computational techniques (e. g., Feynman path-integral techniques), and it is hoped that this study will also provide insights useful in other field-theoretic eigenvalue problems. (Walter S. Zimmermann)

After completion of a preliminary problem in spin relaxation, a literature search pertaining to the effects of internal states on transport coefficients for dilute polyatomic gases revealed a need for deriving a calculable formalism, there being sufficient intractable ones. Rather than using a purely phenomenological approach, an investigation has been begun of the applicability and extendability of the works of Zemach, Scadron, and Snodgrass on scattering theory and tensor spaces to an evaluation of the collision integral. (Warren Wollman)

#### MISCELLANEOUS THEORETICAL TOPICS

A necessary and sufficient condition for a Hamiltonian to yield a Lorentz-invariant S matrix has been found. This condition is

now being applied to the problem of constructing a satisfactory quantum theory of gravitons. (Steven Weinberg)

An analysis of the Einstein equations for a spherically symmetric (Friedmann) universe is being made to determine whether certain observed properties of the universe (formation or clustering of galaxies, etc.) can be explained by examining the solutions of the Einstein equations to first order in perturbations. This is a more detailed analysis than was made by certain previous researchers, including E. Lifschitz.<sup>33</sup> (Peter J. A. Gaposchkin)

A number of attempts at finding finite electrodynamics have been examined. (Owen Fleischman)

Efforts have been made to extend the results of previous work on infrared divergencies in quantum electrodynamics.<sup>34</sup> The properties of the soft photon states and the consequences of energy-momentum conservation on the matrix elements have been studied. (Victor Chung)

Work is in progress to extract numerical results of the variationally derived approximation model, formulated previously, for low- and intermediate-energy rearrangement scattering of an ion-atom system. These and other previous results are being written up. (James Quong)

Work is continuing on the calculation of the shifts and widths of the Coulomb energy levels of  $\pi$ -mesic atoms, using the continuity of the pion wave function at the nuclear surface. Several exact integral relations have been derived for the internal logarithmic derivative in terms of the local potential and effective-mass functions characterizing the nuclear medium. An attempt is being made to formulate an effective-range theory for Coulomb bound states, which would relate all level shifts of a given angular momentum to two parameters analogous to the scattering length and effective range for nuclear scattering in the presence of a Coulomb field. A computer study of the sensitivity of the final calculated level shifts to variations in the input parameters of a simple nuclear model is in preparation. (C. Thomas Mottershead)

The reduction of the n-body phase-space integral to a single contour integral which may be well approximated numerically

has been submitted for publication. This procedure forms the basis of statistical model calculations recently completed.<sup>35</sup> (Graham Campbell, R. J. Riddell, Jr., and J. V. Lepore)

A detailed examination of the errors inherent in the application of an analyticity test<sup>36,37</sup> has been completed. It has been demonstrated that any such application leads to ambiguous results. This work has been submitted for publication. (Graham Campbell)

Neutrino processes are being studied. In particular, calculations are being done using Cabbibo's theory. It is hoped that these will be useful for high-energy neutrino experiments.  $SU_3$  theory has been formulated in a manner differing from that in the literature. (A. Bookstein)

The continuing computational<sup>38</sup> investigation of the effect of azimuthally varying fields (AVF) on the performance of  $\beta$ -ray spectrometers was vigorously pursued, stimulated by the residence at the Laboratory during this period of Dr. Berkqvist of Sweden. A design has been exhibited which has a transmission of 0.8% with a resolution of 0.01%, but whether such a field configuration is conveniently realizable has yet to be learned. To date, the work (which is in the process of being prepared for publication) has demonstrated that AVF is advantageous; there now remains the very extensive program of producing a practical design. (Carl Berkqvist of the Chemistry Department and Andrew M. Sessler)

A systematic method has been developed for deriving the complete set of rigorous relations among the coefficients describing second-order aberrations of general magneto-optical systems possessing a symmetry plane. A number of previously unknown or unfamiliar relations are obtained, together with a few previously known. At the least these relations have utility in providing checks on computer-generated sets of coefficients; it is even possible that some of them may contain useful insights on minimizing specific aberrations of interest. A publication is in preparation. (David L. Judd)

33. E. Lifschitz, "Journal of Physics of the USSR" 10, [2], 116 (1946).

34. V. Chung, On the Infrared Divergences in Quantum Electrodynamics, (Ph.D. Thesis), Lawrence Radiation Laboratory Report UCRL-16202, June 1965 (to be published in Phys. Rev.)

35. Graham H. Campbell, Statistical Model Calculation of High Energy Reactions, (Ph.D. Thesis), UCRL-16315, August 1965.

36. T. Regge and G. A. Viano, Nuovo Cimento 25, 709 (1962).

37. E. Albino, M. Betero, and G. A. Viano, Nuovo Cimento 32, 1269 (1964).

38. Computational work performed in collaboration with Herman Owens.

## ACCELERATOR DESIGN STUDY

The early part of this period was devoted mainly to refining parameter selections and computational studies for the theoretical section of the Design Study Report (UCRL-16000, June 1965). In addition, extensive assistance in writing and editing was given to other groups participating in the study. Shortly after the completion of the report, representatives of the architectural and engineering firms hired by the AEC to examine our estimates of costs and schedules arrived in Berkeley; we participated in the lengthy process of acquainting them with the nature of the project and providing them with the technical information they required. It is planned that their report to the Commission, due in January 1966, will be accompanied by a report from us incorporating additions and refinements to the June report; to this end, we are once again examining our arguments and conclusions, in close collaboration with other members of the study group.

A possible major change in design has been under consideration for some time. A number of different injection schemes have been suggested by various people at Brookhaven, CERN, and LRL, some of them sufficiently attractive to cast doubt on our choice of linear accelerator plus rapid-cycling synchrotron. Under detailed scrutiny, the apparent advantages of alternative methods have largely disappeared, but the question still requires further study. (A. A. Garren, L. J. Laslett, P. L. Morton, and L. Smith)

A further study of the influence of matched straight sections on momentum compaction is being carried out. In general, the insertion of Collins straight sections increases the momentum-compaction factor by at least 1.7, but if the phase advance between straight sections is less than  $\pi$ , the factor is actually reduced from its normal value. More complicated configurations, involving two types of straight section, have also been analyzed. (A. A. Garren)

Further attempts have been made to obtain an analytic solution for the probability distribution of the maximum displacement of the closed orbit generated by random field or position errors. The problem is related to an N-step, two-dimensional random walk with fixed angle between steps, for which one wants to know the maximum excursion in one dimension rather than the usual mean square value. Andrew Sessler recently pointed out an approximate solution to this problem, but we are not yet sure of its validity. (A. A. Garren)

An investigation is under way of the feasibility of correcting field and position

errors on the basis of direct observation of the deviations of the closed orbit. It is, of course, always possible in principle to reduce the deviation to zero at a given number of observation points by making an equal number of adjustments, but this entails an unnecessarily large number of corrections and the deviation can easily get worse at unobservable points along the orbit. In addition, it is necessary to investigate the effect of observational errors and errors in measurement of betatron frequency, the latter being an important quantity in computing the recommended correction. A computer program has been written which permits the calculation and application of corrections under a variety of conditions, using the criterion of minimizing the mean square deviation of the orbit to establish the best correction. A number of exploratory runs have been made for different types of positional errors, various numbers of observation points, and various ways of ganging magnets to make corrections. The tentative conclusion is that this approach is quite practical, though there is much work yet to be done to establish an effective working system. (L. J. Laslett, with Glen R. Lambertson)

In high energy proton synchrotrons, the phase-oscillation frequency is comparable to the revolution frequency. Since it is economically advantageous to concentrate the accelerating stations in azimuth as much as possible, the usual treatment of phase motion in which the accelerating field is regarded as uniform around the ring becomes suspect. Phase motion in the presence of a single accelerating station has been studied analytically and computationally. The discrete nature of the acceleration process gives rise to stop bands, nonlinear resonances, and misalignment effects formally similar to those which trouble betatron oscillations. The parameters selected for the 200-BeV accelerator lie in a safe region. (L. J. Laslett, with K. R. Symon and J. D. Steben of MURA)

The MURA beam dynamics program for linear accelerators has been modified for our purposes, and preliminary studies on our 200 MeV linac injector have been carried out. (P. L. Morton)

At the design intensity of  $3 \times 10^{13}$  protons per pulse, the circulating beam is capable of inducing voltages in the accelerating cavities equal to or greater than the desired applied voltage. A preliminary investigation has been made of the consequences to the rf system and to the phase motion of the beam. The effects do not seem to be serious, provided that a reasonably fast servo loop is included in the rf system to hold the cavity

voltage to the proper amplitude and phase. Transient effects for times shorter than the response time of the loop have been calculated and appear to be negligible. However, these phenomena are not very well understood, and a further exploration will be made. (P. L. Morton)

The nonlinear space-charge problem reported at the 1963 international accelerator conference<sup>39</sup> has been extended analytically and computationally to more realistic situations. The computations of fixed points by and large bear out the analytic results, but indicate significant complications not covered by the simple formulas. Since these considerations have an important bearing on predicted space-charge limits and beam behavior near those limits, we are continuing the exploration of the phenomena. (Frank Sacherer, Lloyd Smith, and Alper A. Garren)

Papers presented at the Frascati Conference on High Energy Accelerators in September, 1965, were:

- Design Study for a 200-GeV Accelerator Facility (L. Smith),
- Design of Long Straight Sections for Synchrotrons (A. Garren),
- Derivation of Corrections to Control the Closed Orbit in an Alternating-Gradient Synchrotron (L. J. Laslett and G. R. Lambertson, read by A. Garren), and
- Resonant Stability Limits for Synchrotron Oscillations [L. J. Laslett, with K. R. Symon and J. D. Steben (MURA), presented by Symon].

Papers were also prepared in connection with the SLAC Storage-Ring Conference on the control of instabilities arising from use of intense particle beams in storage rings and similar devices. These papers, listed below, were concerned with evaluation of the electric and magnetic fields, generated by the particle beam in different environments, that can in-

fluence the stability or instability of the beam. The papers will appear in a SLAC report<sup>40</sup> being issued under the date of August 1965. Related current work concerns the electromagnetic fields that develop in the presence of clearing-electrode structures, which act effectively as transmission lines for high-frequency signals. These may exhibit a resonant response at critical frequencies that depend on the electrode dimensions and on the impedance of the electrical feed.

The papers were:

- L. J. Laslett and A. M. Sessler, "The Asymptotic Perturbation Field of a Longitudinally Bunched Beam Within a Rectangular Pipe with Resistive Walls" -- Paper number 4, p. 23 ff.
- L. J. Laslett, "The Influence of Dielectric Media on the Electromagnetic Fields of a Coasting Beam in a Straight Rectangular Pipe" -- Paper number 8, p. 52 ff. (L. Jackson Laslett)

The decay of the electromagnetic field in a tank with resistive walls after passage of a charged particle has been investigated. The decay is found to be very slow--algebraic rather than exponential--with the consequence that a bunch of particles in a circular accelerator can easily pass through its own wake field many times before the field decays. (Phil L. Morton)

Studies of the instabilities exhibited by intense relativistic particle beams were continued and stimulated greatly by a summer study group at SLAC (Stanford) on the subject. Progress to date has been described in a number of publications,<sup>41</sup> and in two review papers.<sup>42</sup> Work is continuing, while results so far obtained are being prepared for publication. (Andrew M. Sessler)

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39. Proceedings of International Accelerator Conference (Dubna, 1963), p. 897.  
 40. B. Richter, M. Sands, and A. M. Sessler, Eds., "Stanford Linear Accelerator Center Storage Ring Summer Study, 1965, on Instabilities in Stored Particle Beams -- a Summary Report" -- Stanford Linear Accelerator Center Report SLAC-49, August 1965.

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41. L. J. Laslett and A. M. Sessler, Reference 40; p. 23; P. Morton and A. M. Sessler, loc. cit., p. 18; E. Courant and A. M. Sessler, loc. cit., p. 36; C. Pellegrini and A. M. Sessler, loc. cit., p. 61; and R. Briggs, V. K. Neil, and A. M. Sessler, loc. cit., p. 59.  
 42. A. M. Sessler, in SLAC-49, p. 8; A. M. Sessler, Instabilities of Relativistic Particle Beams, Lawrence Radiation Report UCRL-16440, Oct. 1965 (unpublished).

## MATHEMATICS AND COMPUTING SERVICES GROUP

Kent K. Curtis

During the period of this report (May through October 1965) members of the Mathematics and Computing Services Group performed the following tasks for the Laboratory research groups.

## ACCELERATOR DESIGN

AGS Magnet Design

Emphasis has changed from the field properties of various magnet configurations to exploration of the available magnetostatic programs.

The program SIBYL<sup>1</sup> continues to contribute in the investigation of the ring magnet field properties. A major effort was directed toward converting this program for the CDC 6600. Various subroutines were altered considerably to improve the efficiency and speed of this large code. The mesh size was increased by 4000 points. Tests indicate that SIBYL runs about five times as fast on the CDC 6600 as on the 7094.

The program TRIM<sup>2</sup> was reorganized and rewritten. The on-line version of TRIM was replaced by a monitor version. An expanded version of TRIM for the CDC 6600 which uses a much finer mesh was nearly completed.

A study was made of the possibility of incorporating into TRIM a procedure based on Newton's method for the elliptic, quasi-linear partial-differential equations. This method<sup>3,4</sup> promises convergence in fewer iterations and possibly smoother results. (John Colonias, Bob Powell, and James Spoerl for Charles Dols)

1. Joseph Dorst, Experience with Computer Models of Two-Dimensional Magnets, UCRL-11798, March 1965; and J. S. Colonias, Operating Instructions for SIBYL Magnetostatic Program, LRL Internal Report AS/Theoretical/03, July 15, 1964.
2. J. S. Colonias and J. Dorst, Magnet Design Applications of the Magnetostatic Program Called TRIM, UCRL-16382, Sept. 1964.
3. Paul Concus, On the Calculation of Non-linear Magnetostatic Fields, UCRL-16287, July 1965.
4. Alan Winslow, Magnetic Field Calculations in an Irregular Triangle Mesh, UCRL-7784-T, Aug. 1965; Improved Iterative Method for Triangle Mesh Magnetostatic Calculation, UCRL-12132-T, Oct. 1964.

The program FIELD<sup>5</sup> is a new magnetostatic computer program with a general configuration of iron and air and with cylindrical symmetry. This program is intended for the design of the magnet of the proposed 6-meter bubble chamber for the AGS Study Group. This design will serve as a basis of comparison between superconducting coils and copper coils. (John Colonias for Paul Hernandez)

AGS Orbit Studies

Orbit displacement programs (BABRA --described in Physics Division Semiannual Report, UCRL-16099, May 1965, p. 26) were converted for the CDC 6600. (Barbara Levine for Jackson Laslett)

The synchrotron design code SYNCH<sup>6</sup> was improved and converted to the CDC 6600. The pseudo-operation CYC was modified to allow a variable number of iterations in searching for a closed orbit, to print out the intermediate guesses in the orbit search, and to allow the initial guess for the closed orbit to be part of the input. Various information-retrieval routines were incorporated to reduce running time and storage requirements. (Ardith Kenney and Herman Owens for Alper Garren)

AGS Radiation Studies

The program DSN, a neutron transport program, was obtained from Los Alamos and put into operation on our 7094. This program calculates the rate of neutron absorption through different materials. A scattering matrix is formed with a given initial intensity, and the program calculates the final intensity in the various media. A perfect neutron balance is obtained at the end.

A radiation dosage code SHIELD<sup>7</sup> was written. The dose at a field point is proportional to the integral over  $x$  and  $y$  of  $A(x, y) T(x, y)/R(x, Y)$ , where  $A(x, y)$  is the

5. Described in an unpublished paper by ANL-High Energy Physics Div.: General Description of Program FIELD, May 14, 1965.
6. A. A. Garren and J. W. Eusebio, SYNCH --A Computer System for Synchrotron Design and Orbit Analysis, UCID-10153, April 10, 1965.
7. W. S. Gilbert, Shutdown  $\gamma$  Radiation Fields in an AGS Tunnel--Causes and Cures, UCID-10137, Dec. 1964.

relative activation,  $T(x, y)$  is the transmission of  $\gamma$ 's, and  $R(x, y)$  is the distance from source to observer P. The integral was evaluated numerically over the cross section of magnet and coils. (Bob Powell and James Spoerl for William Gilbert)

#### AGS Beam Transport Systems

The program TRANSPORT, written by a group at Stanford University to calculate the shape of the beam as it travels through a variety of beam transport systems, was put into use by the AGS Group, and a CAL-COMP routine was added to allow results (beam envelope and magnet layout) to be displayed on a CAL-COMP plotter. (Bob Powell and John Colonias for Denis Keefe)

#### AGS Magnet Alignment

The program ASTRAL<sup>8</sup> was modified to increase available storage space and decrease execution time. Loss of accuracy observed in inverting large matrices necessitated the conversion of ASTRAL to the CDC 6600 and the use of a new inversion routine.

Several small routines (MATCHCHECK, MATCHHEAD, MATCHSTICK, and COPYCAT) were written in the course of testing inversion routines on the 7094 and the CDC 6600 to compare the accuracy of the results. (Penny Collom for Jackson Laslett and James Braley)

The program DRAG computes matrix elements and vectors for solutions by FE-FIFO-FUM to check the analysis of an overlapping wire surveying system proposed for the AGS as a possible alternative to the ASTRAL scheme. (Penny Collom for Jackson Laslett)

#### Beta Spectrometer

Work was completed on the first phase of a study to investigate the feasibility of using the strong-focusing principle in removing spherical aberrations in an iron-free  $\beta$ -ray spectrometer. The study indicates that if the calculated field configuration can be realized in actual construction, a spectrometer with a transmission of 0.8% with a resolution of 0.01% can be realized. (Herman Owens)

#### 184-Inch Cyclotron

A study of the properties of the beam of the 184-inch cyclotron in the central region of the machine was continued. A program (PINWHEEL<sup>9</sup>) for computer particle orbits in

8. J. A. Braley and Penelope Collom, ASTRAL Surveying Error Analysis Program, UCID-10159, June 1965.

the central median-plane region of a cyclotron was modified to include frequency modulation of the oscillator. The program was used to determine energy variations for particles with various fixed and varying oscillator frequencies. (Victor Brady for David Clark)

### GENERAL PHYSICS RESEARCH

#### Trilling-Goldhaber Group

The program PIOUS5 was revised in two ways: the coding was refined to conserve computer time and memory space, and the various calculations were separated into subroutines to allow adaptation for selective use as CHAOS subroutines (described in PDSR, UCRL-11132, Nov. 1964, p. 51).

Programming changes were implemented in DLHART, a program which computes Dalitz-Heart matrix elements, to reflect continuing theoretical research. As calculations were checked out in DLHART, they were incorporated in CHAOS subroutines for experimental data analysis. DLHART contains sections which makes line-printer contour graphs, using 20 alphabetic characters to denote levels across a  $140 \times 70$  grid; this function was put into subroutine form for other applications.

Adaptation of the Alvarez Group programs TVGP,<sup>10</sup> SQUAW,<sup>11</sup> and ARROW<sup>12</sup> for Goldhaber data analysis was begun. (Robert Goldstein)

Existing EXAMIN<sup>13</sup> routines were maintained, and several were modified for special processing. Two new EXAMIN routines were written and existing programs modified for Experiment 80. (Emmett Burns)

Minor modifications were made to SELECT (PDSR, UCRL-11776, p. 29) to improve tape handling and efficiency. Modifications were also made to process data for Experiment 80.

9. M. Reiser and J. Kopf, Electrolytic Tank Facility and Computer Program for Central Region Studies for the M. S. U. Cyclotron, MSUCP-15.

10. A. D. Johnson and T. B. Day, Three-View Geometry Program, Alvarez Programming Note P-117, June 8, 1965.

11. Orin Dahl and F. T. Solmitz, Alvarez Programming Note P-126 (rough draft), Aug. 25, 1965.

12. Orin Dahl, Alvarez Programming Note P-124 (preliminary note), Aug. 3, 1965.

13. For a detailed description of the EXAMIN System, see Alvarez Physics Note No. 271, Rev., Dec. 1, 1961.

The program FSDPAK (PDSR, UCRL-11776, p. 29) was rewritten to process two-vertex event types of Experiment 08. Tape input-output was also improved. (Bert Albrecht)

The program HIST3D (PDSR, UCRL-16099, p. 27), which draws a series of histograms in perspective, was modified so that fitted curves appear over the histograms. (Noel Brown)

Extensive changes were made to the TGIF<sup>14</sup> program subroutines HZREAD, TGIF (MAIN), FIDGET, VRTX, PICKNO, and INITIL to improve error detection and the handling of topology, event type, and vertex data, as well as to refine fiducial constants and indicative data. Initial work was begun on logical vertex selection in subroutine VRTX and on ionization in subroutine IAN.

Extensive testing and comparison were done by running FSD data through the TGIF-PANAL<sup>15</sup>-PACKAGE<sup>16</sup>-EPC<sup>17</sup>, TFIG-TONG<sup>18</sup>, and TGIF-PANAL-TVGP<sup>19</sup> systems. The present high reject rate shows that the limiting factor is in the apparent confusion of track following. Study has been made of non-real-time filtering programs that might improve this situation.

In order to obtain preliminary results from 80-inch bubble chamber Experiment 80, refinements were made to the PACKAGE program in optical error-setting constants. The beam criterion was inserted by subroutines CONS80, BEAM80, FIDV80, MATCH, SKYZ80, and PDP80.<sup>20</sup> Recalculations of the optical constants and of the field subroutine were made. New strange-particle event-type subroutines ZET22K and ZET28K were written into PACKAGE.

Work was nearly completed on 25-inch bubble chamber Experiment 66. Subroutines TAPE66, PET17K, KET17K, and ZET17K were initially written into PACKAGE for this experiment.<sup>21</sup> A platinum target position subroutine and a  $K_2^0$  decay event type were written while this experiment was still in progress. The subroutine PLATIN was later rewritten with error equations, and retested and refined for a more correct target position. To obtain necessary additional constraints and to handle zero-constraint problems, subroutines TOTLBA and ZEROCT were added to PACKAGE. The event type subroutines ZET07K, KET07K, and PET07K were written.<sup>22</sup> In conjunction with these, a special track-flipping subroutine, CREATE, was added to PANG.<sup>23</sup> Sigma decay marks, effective mass, and transverse momentum calculations have been added to PACKAGE for this experiment. (Jim Miller)

#### Powell-Birge Group

Overall planning was completed on a program, BITSANDPIECES, for establishing and maintaining files which will contain the status of events in the FOG data-reduction system. Programs have been completed for setting up the master list and for incorporating data from about half the various kinds of source tapes. The purpose of this project is to enable the physicists to determine the status of events, and thus to detect bottlenecks, avoid loss of events, and increase efficiency. (Penny Collom and Myron Myers)

A program SANE was written to provide a skeletal logical framework within which users can write subroutines to further the analysis of interesting interactions. Included are special FAIR<sup>24</sup> tape-reading routines, a library-tape concept, event categorization or filtering, ability to easily increase the amount of data associated with an event, selected lists, and selected displays on either the CRT or CAL-COMP plotter. These features are usable either by CALL statements or control cards, or both. A maximum of 500 variables, 260 mass permutation, and 260 chain levels are allowed, and up to 200 displays are

14. A. D. Johnson, Preliminary Trilling-Goldhaber Input Format (TGIF), Alvarez Memo No. P-118 (not for distribution outside the Laboratory).

15. For a detailed report of PANAL, see UCID-1650, Nov. 1961.

16. For a detailed description of PACKAGE, see Barrie Pardoe, Alvarez Programming Notes P-27, May 1962, and P-40, Feb. 1963.

17. Barbara Cottrell, Modified EPC, Alvarez Programming Note P-10, Oct. 23, 1962.

18. This is the new 80-inch version. For a description of TONG program, see Alvarez Physics Note No. 105.

19. For a detailed description of TVGP, see Alvarez Physics Note No. P-117.

20. For a detailed description, see Jim Miller, Trilling-Goldhaber Physics Note 112B.

21. For a detailed description, see Jim Miller, Trilling-Goldhaber Physics Note TG121.

22. For a detailed description, see Jim Miller, Trilling-Goldhaber Physics Note TG139.

23. For a detailed description of PANG, see W. E. Humphrey, Alvarez Programming Notes 111 and 325.

24. See Howard White et al., CLOUDY-FAIR, Data Processing System Reference Manual, UCID-1340, 1960-1964.

available in one pass of the user's data. This program is designed to allow the physicist to change control cards via the remote consoles when the CDC 6600 becomes operational. (Noel Brown and Myron Myers)

The group is considering a computer-controlled bubble chamber film-measuring system. A study showed that the feasibility of such a system is limited only by the amount of computer memory available. A new measuring procedure was established which utilizes software instead of operator control for the bookkeeping aspects. The interface necessary to sequence and service simultaneous measuring machine actions was formulated. Specifications for an adequate computer system have been written and included in a letter of inquiry to be sent to various computer manufacturers. (Myron Myers, Robert Belshe, and Donald Zurlinden)

A comparison of various techniques used in the kinematical fitting of bubble chamber events was begun. Particular attention is paid to events of the type  $K^- p \rightarrow \pi^0 \pi^- \Sigma$  with the further reaction  $\Sigma \rightarrow n\pi^+$  or  $\Sigma \rightarrow p\pi^0$ . The techniques being compared are found in the programs CLOUDY,<sup>24</sup> PACKAGE, SQUAW,<sup>11</sup> and BISE.

In order to provide for direct comparison of the results, the same measurements are used as input for all these programs. A program FREE was written to transliterate cards from Powell-Birge FRANCKENSTEIN format to PANAL input format, including rearrangement of the cards within an event as required, and substitution of one set of fiducials for another.

The kinematical program BISE was written especially to analyze reactions of the above type in which the  $\Sigma^+$  is too short to be measured. The program will use FOG output obtained from a tape prepared by FAIR. A preliminary version of the program has been completed. The program uses the techniques of Lagrangian multipliers, and a least-squares solution in which the constraints are expanded in a Taylor series to first-order terms. As a departure from previous methods, the entire set of linear equations is solved, by use of row pivoting to minimize accumulated errors. During the iteration, if the constraints have not yet been satisfied, step cutting is employed when an iteration fails to decrease the sum of the absolute values of the constraints. Once the constraints have been satisfied, several tests are used to terminate the iteration. These tests guarantee that the current values of the solution satisfy the exact system of equations obtained by taking the derivatives of the constraints (that is, with constraints not expanded in a Taylor series). (Harold

Hanerfeld and Loren Meissner)

#### Miscellaneous Physics

The programs TGIF (which converts FSD data to PANAL output format) and SIOUX (which reduces the data) were modified to handle the data from the latest run on the Bevatron and to run on the 7044 and on the CDC 6600.

Programs have been written to convert FRANCKENSTEIN measurements from the same Bevatron run, as well as data measured at Stanford, so that they can run through SIOUX. (William Gage for William Chinowsky)

Additions were made to MUDECAY (PDSR, UCRL-11132, p. 68), a 7094 FORTRAN IV muon decay spectrum folding program, to produce CAL-COMP plots and to allow more flexibility in input data. (Marjory Simmons for Philip Beilin, Theoretical Physics)

A FORTRAN IV program called ATMOS (PDSR, UCRL-11776, p. 31) was used to calculate the effective atmospheric density encountered by a 125-MeV proton during its motion around the earth. The motion of the proton is that of a particle trapped in the earth's magnetic field. The earth's magnetic field was obtained from a 48-coefficient expansion due to Jensen and Cain.<sup>25</sup> Model atmospheres determined by Harris and Priest<sup>26</sup> and by Francis Johnson<sup>27</sup> were used in the calculations.

The program ATMOS was also used to study some of the invariant properties of trapped-particle motion. Orbits were calculated in a dipole approximation of the earth's magnetic field, and the pitch angles of the paths at the earth's magnetic equator were determined. Invariants calculated from these angles were compared with theoretical determinations of the same invariants. (Victor Brady for Harry Heckman)

The program HYDRION, written originally to calculate eigenvalues and eigensolutions of the one-dimensional wave equation, was modified to compute the integral of the product of bound and unbound solutions of the

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

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

27. Francis Johnson, *Satellite Environment Handbook*, 2nd Edition, (Stanford University Press, Stanford, California, 1965).

wave equation. The calculations were done for various isotopic mixtures of the helium hydride ion. (Victor Brady for Walter Wilson)

A program SIGFIT was written to fit experimental differential and total cross sections and polarizations for nucleon-nucleon interactions for various values of center-of-mass energy  $S$  and momentum transfer  $t$  according to the Regge pole theory. Up to 20 residue functions of the form  $A \exp(Bt)$  are used. The parameters  $A$  and  $B$  are varied by using VARMIN<sup>28</sup> to obtain the fit. The primary purpose is to determine the form of residue functions and the helicity amplitudes. (Thomas Clements for Victor Flores, Theoretical Physics)

## SPARK CHAMBERS

### Lofgren Group

Several programs were written to test various methods of recognizing tracks and fiducial marks on spark chamber film. From the results of these tests, a method of scanning spark chamber film was resolved, and a set of programs reflecting this method is currently being written. These programs will be used to scan the film from Leroy Kerth's DIBOSON experiment. They are as follows:

(a) SAWS. Using the spark chamber automatic system (SASS), one scans along a line starting at an origin  $(x, y)$  and proceeds to a final point  $(x+n\Delta x, y+n\Delta y)$  in increment of  $\Delta x$  and  $\Delta y$ . When a hit (intensity change) on the film is found, a value representing the hit is stored in memory. This program is the basic routine for communication between SASS and the DDP-24 computer, and is used by all programs for scanning and obtaining data from film.

(b) FTIC. Given the necessary data defining a spark chamber, this program scans the film and attempts to determine the defining parameters of all tracks in the chamber. The program always attempts to predict the approximate point in the next gap line, using the first and last point found for calculating the next point. If the program becomes confused, it displays the hits on the DEC-30 CRT and lets the operator determine the next course of action.

(c) B\$01. Given the approximate position of a fiducial, this program scans the film and determines the correct position. The fiducials are represented on the film as black circular dots. Once the program finds the fiducial, it makes several scans across the dot, to deter-

mine an average position for the center.

(d) B\$02. Given the approximate position of a binary data box, this program scans the film and converts the marks to binary numbers. (Donald Zurlinden and Robert Belshe)

Work has begun on a set of track-matching and momentum-estimation routines for Leroy Kerth's DIBOSON experiment. Routine VARCH takes the coefficients  $a_i$  in the power series  $\sum a_i x^i$  and determines the coefficients  $d_i$  in the transformed power series  $\sum d_i y^i$ , where  $x \equiv C_1 y + C_2$ . Routine GETCH takes the coefficients  $a_i$  in the power series  $\sum a_i x^i$  and determines the coefficients  $b_i$  in the corresponding Tchebychev series  $\sum b_i T_i(x)$ . Routine POWANT takes the coefficients  $b_i$  in the Tchebychev series  $\sum b_i T_i(x)$  and determines the coefficients  $a_i$  in the corresponding power series  $\sum a_i x^i$ .

Routine ECONO approximates a polynomial by one of lesser degree. The approximating polynomial is the best fit in the Tchebychev sense on the domain specified. This routine uses VARCH, GETCH, and POWANT. (David Snyder)

The DDP-24 program MICKEY (PDSR, UCRL-16099, p. 29) was rewritten for improved speed. Subroutines for finding fiducials were added. (Leslie Wilson)

### Moyer Group

Work was started on programs for the Perez-Mendez experiment, which will study polarization of neutron and charge. A PDP-5 program to control a Vidicon film scanner has been started, as well as 6600 programs to read PDP-5 output tapes and perform pattern recognition. (Anthony Schaeffer and Leslie Wilson)

Pattern-recognition subroutines were provided for the program WHIRLAWAY, which performs the analysis of spark chamber data from the Solomon and Perez-Mendez double-charge-exchange experiment. Preliminary results indicate that the automatic scanning efforts in this experiment will be highly successful. (Leslie Wilson)

A generalized paper-to-magnetic-tape program P-MAG was written for the PDP-5. Although the program was initially written to process output from a digitized protractor, it is in a form suitable for general use. (Anthony Schaeffer)

Four groups of programs were written to handle the analysis of a spark chamber muon decay experiment. DIG edits the multi-variable-record-length tapes produced by Tramp I and II measuring devices, and puts

28. Write-ups on Z0 E0 Z013 and Z0 E0 Z014 may be obtained from Judith Lawrence in the Computer Center Library, Building 50-A, Rem. 1148.

them into Fortran-compatible format. Input, output, and processing are overlapped to minimize execution time. TRUMP then reconstructs events and performs various checks on scanning accuracy. OSCAR (PDSR, UCRL-16099, p. 30) is similar in purpose to TRUMP. It processes punch-card data gathered on OSCAR measuring devices. FOVA takes the output from TRUMP or OSCAR and makes printer plots and histograms of relevant experimental parameters.

Routine PPLT was modified so that multiple points have special plotting symbols (that is, "\*", 2, 3, 4, ..., 9, A, B, C, ..., Z, "\$" is used to denote 1, 2, ..., 35,  $\geq 36$  occurrences of the same plotted point).

A program ORBUT was written to compute charged-particle trajectories through a magnetic field. The magnetic field  $B_x$ ,  $B_y$ , and  $B_z$  was calculated by using a table of  $B_z$ , Maxwell's equations, and an  $n$ th order interpolating and differentiating routine.

Routine NTPO, used by ORBUT, was written to allow simultaneous interpolation and first-derivative and second-derivative calculation for a tabulated function by using an  $n$ th-order polynomial fit. (David Snyder for Howard Weisberg)

In the analysis of experimental elastic scattering of strongly absorbed ions,<sup>29</sup> the program PHAST (PDSR, UCRL-16099, p. 28) was again reparameterized with respect to the phase shift, in order to study the effect on the theoretical formulation of the nuclear radius, which is dependent upon the phase-shift parameter. (Claudette Rugge for Evangelos Hadjimichael)

#### Crowe-Haddock Group

MOMRANGE is a 7094 FORTRAN IV program which calculates the momentum loss, by Sternheimer's equations,<sup>30</sup> of a  $\pi^+$ , a  $\mu^+$ , and an  $e^+$  in traveling through aluminum, polystyrene, water, and polyethylene. Integration is done by the Adams-Moulton method, using a variable step size.

A program MOMENTUM was written to fit, in the least-squares sense, a set of values of range and the corresponding momenta to a first-degree polynomial, which is obtained by expressing the range-energy relation in logarithmic form.

PLANES was written to determine the equations of the planes of a series of scintillators and wire chambers, to perform a matrix transformation to a new coordinate system, and to fit an irregular surface of a Cerenkov counter to a series of planes. The program HISTPO transforms wire-chamber addresses to inches, determines a momentum from two wire addresses, and then erects a histogram of momenta in increments of 5 MeV/c. The program HISTOGRAM, which was partially written by Jerry Helland, is used to study the target spark chambers used in the  $K^+$  Bevatron experiment of the Crowe Group. The subroutine FGEN generates either of two wire-chamber addresses when one is given and a primary track is observed in the exit spark chamber. [Edna Williams for Michael Zeller, Jerry Helland (UCLA), and Kenneth Crowe]

Development of the programs CRWEXP and VIDATA (PDSR, UCRL-16099, pp. 29, 30) for analysis of the Crowe Bevatron experiment was continued. The VIDICON data turned out to be quite irregular, causing trouble in the pattern recognition parts of VIDATA. (Leslie Wilson)

#### CHEMISTRY

Several programs were written for the analysis of angular distributions of fission fragments. Various refinements have been applied to  $\alpha$ -particle-induced fission of  $Bi^{209}$ ,  $U^{238}$ , and  $Au^{197}$  at bombarding energies from 30 to 110 MeV. The basic scheme of the program, which is called P-FIT, is to transform the measured laboratory-system angular distributions of the fission fragments to the center-of-mass system, and then normalize the data to a c. m. angle of 90 deg by fitting to a sum of even Legendre polynomials. A theoretical anisotropic expression for a normalized c. m. angular distribution is then fitted by least squares to a parameter  $P = \langle I \rangle^2 / 2K_0^2$ , where  $\langle I \rangle^2$  is the mean square value of the angular momentum imparted to the fissioning nucleus, as obtained from the optical model. A refined version of the program includes angular distributions for each value of  $I$ , which are used as weighting factors to obtain  $K_0^2$  directly. An extension of the program was begun which includes the effect of competition between fission and neutron emission and the theoretical calculation of the effective  $K_0^2$ . (Claudette Rugge for Shyam Kapoor)

An exponential decay program called RAD (PDSR, UCRL-10572, p. 72) was modified to accept 20 input components, for ease in fixing known components or half-lives. The program was applied to an experiment designed to find the total reaction cross section

29. Evangelos Hadjimichael, Elastic Scattering of Strongly Absorbed Ions (Ph. D. thesis), UCRL-11781, April 1965.  
30. Phys. Rev. 88, 855 (1952), Eq. (13); Phys. Rev. 91, 265 (1953), Eqs. (48) and (49).

of  ${}_{83}\text{Bi}^{208} + {}_2\text{He}^4$  at 120 MeV and compare this value with the theoretical optical model. The experimental decay curve was successfully analyzed for 12 known isotopes. (Claudette Rugge for Ray Gatti)

The program STUMBLE (PDSR, UCRL-16099, p. 30) was rewritten to allow greater flexibility in the fitting function that defines the fission branching ratio as a function that defines the fission branching ratio as a function of excitation energy, as formulated by Plasil.<sup>31</sup> The new program, called VANDEL, was reparameterized to fit the neutron level density as a function of excitation energy upon multichance fission. Calculations were made with respect to a new mass formula. An option was added to obtain the fission branching ratio by fitting data or by forming a parameter grid of excitation energy versus neutron level density.

Extensive use of the program has shown that more work should be done on both the  $\psi^2$  minimization routine and the parameterization of the neutron level density. (Claudette Rugge for Arastoo Khodai-Joopar)

The programs FFGSORT, D12CALIB, MASS SORT, PLOT, and BAR (PDSR, UCRL-11446, p. 26) were modified to use the 512-channel Nuclear Data tapes. Work was begun on rewriting these programs for generality, clarity, and simplicity in use, with the ultimate goal of converting to the CDC 6600 VISTA system. (Claudette Rugge for Eiko Takekoshi, Rand Watson, and Harry Bowman)

A program called PLOT was written to do contour plotting. The contours are indicated by numerous symbols plotted at points along each contour. Each contour has a different symbol associated with it. The region of the plot is an equilateral triangle with the lower left corner at the origin. (William Dempster for Krishna Kumar, Michigan State University)

Some preliminary work was done on a liquid-drop model of nuclear fission. The drop was assumed to be two spheroids connected by a hyperbolic neck. Any configuration could, then, be described in terms of five parameters. The project consisted of two stages: first, to find a choice of the five parameters such that the energy of the drop was at a saddle point; and second, to calculate the dynamics, starting from the saddle point. A recursion relation was worked out for the hypergeometric function that arose. Work on

this project has been discontinued. (William Dempster for Hiroshi Baba)

The program MICRO was written to calculate the coupling terms for inelastic scattering of nucleons of a particles based on a microscopic description of the nuclear state. (Edna Williams for Norman Glendenning)

Modifications were made to SCAT (elastic scattering program, PDSR, UCRL-11466, p. 25) to provide CAL-COMP plots. A version was also written to provide plots on the monitor output tape. (Bert Albrecht for Ed Boschitz)

The program DIFFER (PDSR, UCRL-16099, p. 30) was modified for speed and accuracy. DIFFER solves the coupled complex differential equations for scattering of nucleons or a particles from an even nucleus in which the coupling between the excited states of the nucleus is explicitly introduced. (Noel Brown for Norman Glendenning)

A general CAL-COMP plotting subroutine TLTFIT was written to be used by programs fitting data by means of least squares. The user may specify how many curves to plot on one graph, whether or not to connect the points, and whether or not to draw error bars. (Bert Albrecht for Stanley Thompson)

The program TRITENS (PDSR, UCRL-11132, p. 72) was revised to provide a new input-output option and to allow use of 46 dimensional matrices. A bug in the program RACAH<sup>32</sup> from the National Bureau of Standards was found and corrected. The program BETABLE (PDSR, UCRL-11132, p. 56) was revised to allow an indefinite number of matrix elements.

A program was written to find second derivatives of eigenvalues of matrices of the form  $A = \sum x_i A_i$  by use of eigenvalues and eigenvectors at the point  $(x_i)$ . This was inserted into a minimizing program that requires second derivatives and is used to replace VARMINT<sup>28</sup> in program BETABLE for small input matrices. For larger input matrices, an approximate second derivative using only first derivatives of eigenvalues has been used successfully, starting at points not too far from a minimum. (Thomas Clements for John Conway)

The programs DEUPOL and DEUVAR were written to minimize a quartic  $\chi^2$  function of eight variables in an eight-dimensional

31. Franz Plasil, Energy Mass Distributions and Angular Momentum Effects in Heavy-Ion-Induced Fission (Ph. D. thesis), UCRL-11193, Dec. 1963.

32. C3 E0 RACA write-ups may be obtained from Judith Lawrence in the Computer Center Library, Building 50-A, Rm. 1148.

rectangle. The function represents an experimental determination of the tensor polarization of the deuteron. DEUVAR uses VARMIN; DEUPOL uses a second-derivative method for minimization. Analysis by Dr. Baumgartner indicated that all minima should lie in the vicinity of two lines in the region. The programs showed that the lines represented valleys. No minima were found. (Thomas Clements for Eugen Baumgartner)

A previously written program MYSTIC (PDSR, UCRL-16099, p. 30), which analyzes exponential decay data with superimposed oscillations, was modified to consider not only integral periods, but fractional periods as well. The analysis of this program was analogous to a simplified Fourier analysis in which square waves are used instead of sines and cosines.

A program AUTO was written to determine the power spectrum of the same data; the approach used was that of Blackman and Tukey.<sup>33</sup> The autocorrelation was computed, and then the Fourier transform was taken, yielding the power spectrum of the given data. (Esther Coleman for Eckart Matthias)

Runs were made, using the program UNFOLD (PDSR, UCRL-16099, p. 30), which demonstrated the incompatibility of the given data with the required kernel, as well as the great sensitivity of the solution with respect to the kernel. (Eric Beals for Eckart Matthias)

A system of programs, including ALAGA, ALAGA3, and ALAGA5, was written to calculate energy spectra for two- and three-particle excited states, using models developed by Dr. Gaja Alaga. The program was applied to the elements mercury, gold, and cadmium; electric quadrupole and magnetic dipole transition probabilities were calculated for mercury and cadmium. (Deanna Wilber and Robert Goldstein)

A program PUZZLE was written to design printed circuit boards by use of horizontal and vertical grids. The program finds the shortest path between two specified points on the board. The CAL-COMP plotter is used for graphical output, which also shows the power and ground buses, power and ground connections, connections between cans, and connections to the connector edges. (Deanna Wilber for Ronald Zane)

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33. R. B. Blackman and J. W. Tukey, The Measurements of Power Spectra (Dover Publications, New York, 1958).

## INORGANIC MATERIALS

The program NEWTON was written to solve a problem that arises in ellipsometry calculations. The problem deals with three simultaneous nonlinear "equations" in three unknowns, where each equation is in actuality a set of several. Newton's method is employed for the solution. To allow the greatest flexibility possible in the types of equations that can be handled, numerical differentiation is employed to obtain the necessary partial derivatives. (Gerald Litton for Rolf Muller)

Mathematical consulting services were provided in a preliminary study of a pair of coupled nonlinear differential equations in a boundary problem with conditions at infinity. Further study is required. (Loren Meissner for Donald Olander and Robert Krakowski)

The program THERMO was written to obtain a value of the work function for single-crystal emitters of a thermionic diode; the work function must be known if the basic phenomena are to be understood. Because a high temperature and a high vacuum are necessary for obtaining work function data, this program was needed to ascertain that the stringent experimental conditions have remained constant during the time required for data acquisition. (Edna Williams for Ronald Wichner)

The region in which certain approximations were applicable was investigated, by use of a functional form developed for Daniel Fiat for his nuclear magnetic resonance data. (Eric Beals for Robert Connick)

Two interpolation and plotting programs, HANDYT and CESPLOT, were written. (Eric Beals for William Gardner)

## BIOLOGY

### Biomedical Research

The following papers were published or accepted for publication during this period:

1. Grove Nooney, Iron Kinetics and Erythron Development, *Biophys. J.* 5 (1965).
2. Grove Nooney, An Erythron-Dependent Model of Iron Kinetics, UCRL-16406, Sept. 1965.
3. Grove Nooney, Allocation of Errors to Theory and Experiment, *J. Theoret. Biol.* (to appear).
4. Mark Horovitz and Grove Nooney, On Interpreting Compartmentalization Experiments, *J. Theoret. Biol.* (to appear).
5. Grove Nooney, Iron Kinetics and Erythron Development, Lecture to Hematology Seminar, Stanford School of Medicine.

In radiation hypophysectomy, the energy

distribution of the irradiating particle beam is modified by passage through slabs of material. These slabs are made into a complex rotating or oscillating absorber such that the desired value of the sum of their effects on the ionization will be produced by the beam at a given distance from the source. A program IONPIE has been written to find the combination of number, size, and thickness of slabs which will best approximate, in a least-squares sense, a specified one-dimensional distribution of ionization density.

A method and formulary have been devised to permit choice of beam aperture to obtain lethal irradiation of selected tissue volumes while minimizing damage to other tissue.

Work is in progress on a program to draw isodose contours on the CAL-COMP plotter from the output of PITARY, a program which computes the radiation dose in a plane passing through the head of a subject undergoing radiation hypophysectomy. (Marjory Simmons and Grove Nooney for John Lyman)

Analysis has been begun of the correlation between the output of neighboring scintillation counters. Application will be to the measurement of regional blood flow in tissue. (William Hogan for Robert Hippenstelle)

A program UNFOLD(D) was written to compute an electron energy spectrum from  $\beta$ -ray spectrometer data. The program uses the Gold-Scofield method of solution for a linear integral equation, the kernel of which is obtained from the measurement of known spectra. More accurate kernel representations are being sought. (William Dempster for John Lyman)

Work has continued using program LSQVMT to fit various theoretical forms to data on the survival of irradiated cells. (Laurence Lawler and Mark Horovitz for Cornelius Tobias)

Analysis of human calcium and strontium kinetics has been continued with data from the whole-body counter and from plasma determinations. Preliminary analysis of the data by use of the program SAAM 22 (National Institute of Health) (PDSR, UCRL-16099, p. 32) has indicated a number of preferred compartmental models. Several of these models are presently being studied to determine their compatibility with the data. (Thomas Mahan and Penny Collom for Thornton Sargent)

A program IRK is being developed to aid in the analysis of iron kinetics in the human

by computing the values of parameters of a model which best fit experimental data. The goal of this work is the differential diagnosis by computer of pathological iron use.

Work has been begun on a related program RETIC for the analysis of the production and release of reticulocytes from the bone marrow into the blood. This program may lead to the definition of the release function of red blood cells from the bone marrow. (Kenneth Wiley for H. Saul Winchell)

A program SIMDIF using FORTRAN subroutine RW INT was written to solve a pair of simultaneous differential equations of the form  $dx/dt = f(x, y)$ ,  $dy/dt = g(x, y)$ . The equations are from the theory of irreversible thermodynamics. (Thomas Clements for David Zelman)

A CAL-COMP plotting program RATGPH, which plots rat weight against age, was added to the Rat Test package. In addition, minor modifications were made and assistance with the package was given. (Eric Beals for Patricia Durbin-Heavey)

A simulation procedure was designed for the evaluation of performance of radiation collimators. (Grove C. Nooney for Hal Anger)

A program ROTOR, to establish a model for the radiosensitivity of the vestibular mechanism, has been started. (Kenneth Wiley for Larry McDonald)

A program CUTOFF was written to provide polynomial fits to data from irradiated animal cells. (Marjory Simmons for John Lyman)

First and second derivatives of data requiring varying amounts of smoothing were computed by use of programs POLFIT2 and LYMFIT, fitting polynomials of different degree to sections of each set of data. The derivatives were computed from the fitted functions. (William Hogan for John Lyman)

Tests continue of a method<sup>34</sup> and an implementing program NMOD3 for the determination of erythron behavior. Nontrivial testing data were obtained through the explicit solution of certain integrodifferential equations. (Thomas Mahan)

#### Biodynamics

A program KKTRAN was written to aid

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34. Grove C. Nooney, Iron Kinetics and Erythron Development, UCRL-11879, Rev. 1, May 14, 1965.

in the analysis of optical rotary dispersion measurements by computing the Kronig-Kramers transform of a set of data and plotting the measured and transformed functions. (Eric Beals for Edward Drätz)

A model, called CELDIV, of a growing population of cells was devised and tested. The purpose of the model is to explain, on the basis of certain simple assumptions about cellular growth processes, observed variations in the distribution functions of cell volume. The preliminary model showed the required qualitative behavior. (Eric Beals for Edward Holmsen and Vivian Moses)

Quantitative analysis of the kinetics of tracer carbon in the biochemical pathways of photosynthesis has been started. Differential equations containing unknown parameters describe the kinetics, and a program DIFEQS has been written to determine the parameter values that yield a solution of the differential equations best fitting the experimental data. (Eric Beals and Mark Horovitz for James A. Bassham)

#### Health Chemistry

A program CARFIT, which uses the least-squares version of VARMIN, was written to fit data representing tumor weight versus time to a function of the "Gompertzian" form:  $W \cdot \exp\{A[1 - \exp(-Bt)]/B\}$ . (Thomas Clements for Patricia Durbin-Heavey)

#### Health Physics

A program PRODINT was written. This code computes radiation dosages by numerical integration of the product of cross section times particle flux. (Thomas Clements for Alan Smith and Wade Patterson)

#### ELECTRONICS ENGINEERING

Mathematical consulting services were provided on the question whether a given representation of a network impedance could be extended from a lumped (finite) to a distributed (infinite) network. Conditions for the convergence of the infinite representation were discovered. The result will be published as an appendix to a forthcoming engineering research paper.<sup>35</sup> (Loren Meissner and Anthony Schaeffer for Joseph Katz)

The program EIGLIM, a booster circuit code, was modified so that the impedance associated with any one set of capacitors can

be changed with a corresponding change in the impedance involving the resistors, since the changes will affect both the real and imaginary parts of the complex impedance. (Bob Powell for Henry Lancaster)

A program POWER has been written in 7044 FORTRAN IV to supply a Fourier analysis of the 88-inch cyclotron power supply and a CAL-COMP amplitude-versus-frequency diagram. (Marjory Simmons for Bob Smith)

#### Magnet Test

All the work reported below was done in connection with magnetic field measurements taken by the Rapid Mapper.<sup>36</sup>

The program PLOTOR (PDSR, UCRL-16099, p. 33) was modified to give a more general routine and increase its running efficiency.

The program HARQUAD (PDSR, UCRL-11466, p. 22) was modified to make it compatible with a new data format.

The program FIXIT (PDSR, UCRL-11132, p. 45) was expanded and renamed OMNIBUS. OMNIBUS is capable of performing all data processing beyond the CERTFY level (PDSR, UCRL-11132, p. 45). Through control-card options, the user may make corrections to data, obtain matrix printouts of data, combine sets of field measurements for purposes of comparison, compute a set of reference measurements to which other measurements are to be leveled, level a map of measurements to a set of reference measurements, or plot various functions of  $x$  position or current. Any combination of the above operations may be performed upon any number of data sets during one run.

FILMER was written to provide selective record and file duplication for up to three input tapes. Not only is selective duplication provided for, but also one or more records may be combined to form a single record, or characters and words within a record may be manipulated by means of shifting, deletion, or replacement.

A package of tape-handling routines was written using LRLRW.<sup>37</sup> This package includes input and output of binary records,

35. J. E. Katz, Pole-Zero Analysis of a Distributed System, LRL Internal Report AS/MAIN Ring/04, October 18, 1965.

36. Peter Watson, Brief Description of Operations and Performance Specifications of LRL Rapid Magnet Field Mapping Systems, Engineering Note MT-164, Aug. 8, 1963.

37. Described in LRL 7094 IBSYS Users' Manual, p. 102.2.2, available from Judith Lawrence, Computer Center Library, Building 50-A, Rm. 1148.

writing end-of-file marks, rewinding, and tape positioning by file and record count.

A program CON88 was written to convert magnet measurements taken for the 88-Inch Cyclotron to the format of data being processed in the CERTFY-OMNIBUS System. The original tapes of 88-inch measurements are card images and are unprocessable on current routines. (Bert Albrecht)

#### MISCELLANEOUS

Work was completed on a report by Paul Concus, On the Calculation of Nonlinear Magnetostatic Fields, UCRL-16287, July 1965, concerning an iterative procedure to find the numerical solution of a two-dimensional quasi-linear, elliptic partial-differential equation arising in magnetostatic field problems. Two talks based in part on the report were given—one at the Symposium on the Numerical Solution of Partial Differential Equations, University of Maryland, and the other at the International Symposium on Magnet Technology, Stanford Linear Accelerator Center.

Work was begun in investigating the theoretical aspects of elastic wave reflection and refraction at a plane boundary separating two semi-infinite media. The purpose is to resolve certain problems arising in nondestructive testing. (Paul Concus for Richard Nickerson, Mechanical Engineering)

Consulting service was provided to Atomic Energy of Canada, Ltd., in their efforts to design a high-gradient magnet for their proposed cyclotron. TRIM is being used. (John Colonias)

#### Director's Office

A new budget program, FORCAST, written in FORTRAN IV for the 7094, was used in preparing the Laboratory Operating Plan for the Fiscal Year. The budget effort plan, computed by SKED92 (PDSR, UCRL-11132, p. 76), is expressed in dollars and man-years of productive effort. FORCAST is designed to convert the yearly effort plan to a monthly effort plan. The man-years of effort budgeted for each subprogram is further subdivided by department and converted to a monthly effort pattern which also takes into account projected vacation and sick leave patterns and scheduled holidays, as well as fluctuations in the hiring of new personnel. Forecasts of the monthly effort and resultant costs are compared with actual monthly patterns as they occur in the course of the fiscal year. Variances are recorded and analyzed for their effect on the Laboratory's budget. (Ardith Kenney for George Pappas)

#### Salary and Wage

A general-purpose sort routine, SORTOF, was written and debugged. It uses four scratch tapes and two disc file areas. The user has complete control of the input of the data to be sorted and the destination of the final sorted information. Data are separated into raw data and ordered keys. The data are put onto disc storage for later retrieval. The keys are sorted on the first pass, using BCSORT. Then, two-way merges of strings of keys take place until the keys are completely ordered. On the last pass, the raw data are retrieved from the disc and given to the user's output.

A control program, ASK, was developed which controls the use of the subroutine SORTOF to provide flexible sorting of salary and wage data. Control cards allow the user to specify the sequence of input data columns which define the sorting key, to delimit the actual input records to be sorted, to direct the disposition of the output, and to specify several distinct sets to be sorted in a given run. (Myron Myers for Mary McCaslin)

#### MATHEMATICS AND COMPUTING

Development was continued on numerical methods for (a) solution of systems of linear equations, (b) solution of first-order systems of differential equations (initial-value problems), and (c) discrete harmonic analysis and synthesis. Current trends in hardware development were taken into account as well, such as increased significance of arithmetic operations. Programs were completed in each of these areas:

The program LINIT solves systems of linear equations (including ill-conditioned systems, matrix inversion, and determinant evaluation) by Wilkinson's method,<sup>38</sup> using double-precision scalar products.

The program ZAM solves differential equations by the Adams-Moulton method, using a Runge-Kutta variant discovered by Zonneveld<sup>39</sup> for starting; to provide variable but controlled step size.

The program HAS performs discrete harmonic analysis and synthesis, using double-precision scalar products. (Loren Meissner)

A study was made of a pattern-recognition program developed at Brookhaven National

38. J. H. Wilkinson, Error Analysis of Direct Methods of Matrix Inversion, Assoc. Comp. Mach. J. 8, 284 (1961).

39. J. A. Zonneveld, Automatic Numerical Integration, Mathematisch Centrum, Amsterdam, MCT-8, p. 23.

Laboratory for the processing of bubble chamber film. The feasibility of writing a similar program in FORTRAN to make use of the available facilities of the CDC 6600 was considered. (Harold Hanerfeld)

Routines (originated at Livermore) for calculating various Bessel and  $\gamma$  functions were converted from FORTRAN II to FORTRAN IV, for the 7094 and the CDC 6600. These routines include Bessel functions  $K_n(x)$ ,  $I_n(x)$ ,  $Y_n(x)$ , and  $J_n(x)$ , and spherical Bessel functions. The I, Y, and J functions were done in both single and double precision. Other routines converted include the  $\gamma$  function for both real and complex arguments, natural and common logarithms of the  $\gamma$  function, and the elliptic integral of the third kind. (Deanna Wilber)

The program VARMIT, which determines a local minimum by the method of Davidon,<sup>40</sup> was revised to include some minor changes in method and to improve the input-output options. This revision was also made compatible with CHIPPEWA FORTRAN on the CDC 6600. The LSQVMT program, which uses VARMIT to determine the best (in the least-squares sense) set of parameters of a functional form and a set of data, was revised to improve its input-output and make it compatible with CHIPPEWA FORTRAN.

Three other minimization programs, MINSER (a nongradient method due to Powell<sup>41</sup>), CONSER (a variation of MINSER), and SIPMIN (a simplex method due to Nelder and Mead<sup>42</sup>) were revised for compatibility with CHIPPEWA FORTRAN.

The nonlinear least-square program of Marquart (G2 NLIN)<sup>43</sup> was also made compatible with CHIPPEWA FORTRAN.

By use of a new method of Powell,<sup>44</sup>

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40. William C. Davidon, Variable Metric Method for Minimization, Argonne National Laboratory Report ANL-5990-Rev. 1, Nov. 1959.
41. M. J. D. Powell, An Efficient Method for Finding the Minimum of a Function of Several Variables without Calculating Derivatives, *Computer J.* 7[2], 155 (1964).
42. J. A. Nelder and R. Mead, A Simplex Method for Function Minimization, *Computer J.* 7[4], 308 (1965).
43. Donald W. Marquart, Least-Squares Estimation of Nonlinear Parameters, (G2 DPE NLIN), SHARE Distribution No. 3094, March 1964.
44. M. J. D. Powell, A Method for Minimizing a Sum of Squares of Nonlinear Functions without Calculating Derivatives, *Computer J.* 7[4], 303 (1965).

a program SSQMIN was written which minimizes the sum of squares of nonlinear functions without calculating the derivatives. Also a variation, LSQMIN, was written which does least-square minimization. These programs are being rewritten to improve their performance and to make them compatible with CHIPPEWA FORTRAN.

The minimization routines available were run on the 7044 with several different functions and different starting values to give a feeling for the best application of the different programs. (Eric Beals)

### Systems Programming

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

#### CDC 6600 Systems

Because of unavailability of a working system and of adequate documentation of the SIPROS System, the decision was made to adopt and adapt the CHIPPEWA Operation System (COS) for the CDC 6600.

Programs were written for the CDC 6600 to perform the 1460 support functions for the 7094 of card to tape, tape to printer, and tape to card. These programs will run in peripheral processors and will not conflict with normal job processing in the CDC 6600 itself. Programs were begun to produce output tapes on the CDC 6600 which can be used to drive CAL-COMP plotters on the 1460 and the 7094A CRT. The Programmer File System was specified and coding was begun for implementation of this function. The 6411 (I/O Module) system was specified for its initial implementation and coding was begun. The Disc Executive was specified and coding was nearly completed. A new technique was developed for writing systems programs of this sort. Check-out of coding to utilize teletypes on the synchronizer being built for Berkeley from the Livermore design was nearly completed. A Handbook for Chippewa Users was written and published in the Computer Center Newsletter (Volume 2, Numbers 18 and 19). A version of SAMPLER for COS was written. The PPU assembler that runs on the 7094 was modified to produce COS format binary decks. (Jerry Borges, Bill Benson, Jane McDonald, Walter Hutchinson, Samuel Penny, Douglas Brainard, David Stevens, and Charles Stevenson)

Support was given to the CDC 6600 Users' Organization, VIM. Kent Curtis was elected President of this organization. David Stevens is a member of the Software Evaluation Committee, and Bill Benson is a member of

the Time-Sharing Committee. LRL personnel was instrumental in getting CDC personnel from Chippewa Falls to attend a workshop in Albuquerque, New Mexico, with 6600 users, to discuss problems of the Chippewa Operating System and consider the suggested and required modifications thereto.

#### 7094 Systems

Diprogramming modifications were made to use the Channel H clock, to eliminate dumps caused by running overtime, to improve the readability of on-line output, and to correct all known bugs. The diprogramming project is now considered to be complete. (Doneley Watson, Myron Myers, Gayle Wampler, and Bill Benson)

The time card processor AUDIT1 was rewritten and debugged. The report generator AUDIT2 was modified for greater efficiency, resulting in a 75% reduction in running time. A program AUDIT3 was written to extract data by account number to facilitate special reports. (Robert Belshe)

#### 1401/1460 Systems

A program COSTLESS was developed to produce input tapes acceptable by Chippewa FORTRAN from cards or BCD tapes. It replaces an earlier program, COSTMORE, which involved a preliminary pass through the 7044 prior to 1460 processing. All input for the CDC 6600 is currently being processed through COSTLESS. (Walter Hutchinson and David Stevens)

The TAPE DUMP program was modified to handle tapes in CDC 6600 format (20 octal digit groups instead of 12), and corrections and improvements were made to the existing 7094 portion of the program. (Walter Hutchinson)

The function of the 1401 paper-to-magnetic-tape program DOB was expanded to include some error detection and partial error correction, as well as other changes requested by the users. (Robert Belshe)

A "KWIK" permuted title index program, received from IBM, was used to produce an index of documents relating to the CDC 6600. (Samuel Penny)

#### DDP-24 Systems

A DDP-24 program SASP was written to plot 7094 and 7044 CRT plot tapes on the SASS scope so that film may be exposed by use of the attached camera. The display may also be monitored on the DEC 30 scope. The

purpose of the program is to relieve the 7094-A of this utility task. The program is also designed to run concurrently with the CAL-COMP plotter utility routine already available on the DDP-24. Although the program is finished, certain hardware problems must be solved before it can become completely operational. (Bill Benson)

The two CAL-COMP plotters purchased for the CDC 6600 were installed on the DDP-24, and a utility program CAL-COMP was written to drive both plotters simultaneously.

A chain technique for the DDP-24 (similar to 7094 FORTRAN II) was designed, and the required subroutines CHAIN and LINKGEN were written. (Robert Belshe)

#### PDP-5 Systems

Some improvements were made to the existing version of the program ASSM, which assembles PDP-5 programs on the 7094, and work was started on converting it to run on the CDC 6600. (Anthony Schaeffer)

#### PDP-7 Systems

The PDP-7 computer, to be used in pulse-height analysis, arrived in late September. A debugging package, DEBUG (similar to that on the PDP-5), was written for the PDP-7. (Myron Myers and Donald Zurlinden)

An assembler and simulator for the PDP-7 was written which runs on the 7094. The assembler generates a magnetic tape containing the object code and is converted to paper tape on the DDP-24. (Myron Myers)

### COMPUTER OPERATIONS

#### Hardware Development

Site preparation for the CDC 6600 was brought to 95% completion in Building 50-A. Plans were developed for moving the IBM 7044 to Building 70-A. Modulux buildings were installed to house the VISTA system, which is part of the CDC 6600. Two motor generator sets and their control cabinets for the CDC 6600 were installed, and performance load tests were made. A CDC 690 magnetic tape certifier was installed in August.

A program was established to certify new tapes on a sample basis. This sample testing program insures that the Laboratory retains a high standard of error-free magnetic tape. A similar program is currently in use to recheck all tape that is returned to Computer Operations before it is reused on the computers. (Paul Rhodes and Marvin Atchley)

PHYSICS RESEARCH

Edward J. Lofgren in charge

PROTON-PROTON ELASTIC SCATTERING

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

At 3, 5, and 7 GeV/c the p-p elastic scattering cross sections have been measured for momentum transfers in the region  $-t = 0.01$  to  $5 (\text{GeV}/c)^2$ . The Bevatron external proton beam provided the source of incident protons. Targets of polyethylene and carbon were used for scattered momenta between 500 and 4000 MeV/c, and a gaseous hydrogen target was used for scattered momenta below 600 MeV/c. Three separate secondary momentum channels in all were used. The protons scattered backwards in the c.m. system were detected with scintillation counters following analysis with a magnetic spectrometer. With a few exceptions, the statistical errors are smaller than 1% for the lower momentum transfers, and increase to 5% for 90-deg 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, in agreement with the predictions of the statistical and other phenomenological models. The well-known shrinking of the diffraction pattern is observed, and measurements at momentum transfers in the Coulomb interference region give values for the ratio of the real to the imaginary parts of the forward scattering amplitude  $\rho = -0.43$  at 3 GeV/c,  $-0.39$  at 5 GeV/c, and  $-0.34$  at 7 BeV/c.

Preliminary results of this work have been published.<sup>1</sup> The analysis is now complete and a paper will be presented at the 1965 Los Angeles meeting of the American Physical Society. A detailed description of the results will be published in Physical Review.

$\Sigma\Lambda$  RELATIVE PARITY

Bruce Cork, Richard L. Crollius,†  
Denis Keefe, Leroy T. Kerth,  
and W. A. Wenzel

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\* Present Address: Pan American World Airways, Guided Missile Range Division, Patrick Air Force Base, Florida.

† Present Address: Aero Space Corporation, San Bernardino, California.

1. Preliminary results were presented at the International Conference on High Energy Physics, Dubna, U. S. S. R., August 5-15, 1964.

A polarization measurement in spark chambers has been completed on  $\Sigma^0$ 's produced in  $\pi^- + p \rightarrow \Sigma^0 + K^0$  in the  $\pi^-$  momentum region 1200 to 1400 MeV/c. A measurement of the  $\Sigma\Lambda$  relative parity was planned, using Dalitz decays of the  $\Sigma^0$ 's. The parity measurement requires polarized  $\Sigma^0$ 's. The  $\Sigma^0$  polarization appears to be generally large, although of opposite sign for forward and backward  $\Sigma^0$  production; however, there are not enough Dalitz decays to permit a parity measurement.

The analysis is now complete and the final results have been issued in a Laboratory Report.<sup>2</sup> The differential cross-section measurements are presented for the reaction above. The differential cross sections remain unchanged, within the limits of statistics, from 1200 to 1400 MeV/c. A measurement of the  $\Sigma^0$  polarization indicated that the polarization may be changing rapidly with beam momentum, but poor statistics prevent establishing this conclusively.

$K^-$ -PROTON INTERACTION

Edgar F. Beall,‡ William R. Holley,  
Denis Keefe, Leroy T. Kerth,  
John J. Thresher,\*\* Ching Lin Wang,††  
and W. A. Wenzel

Differential cross sections for elastic  $K^-$ -proton scattering have been measured at incident kaon momenta ranging from 700 to 1400 MeV/c. A total of 17 000 elastic events were observed with narrow-gap cylindrical and parallel-plate spark chambers. Least-square fits of Legendre polynomial power series to the differential cross sections require fifth-order terms in the region of the suggested 1765- and 1815-MeV resonances. Sixth-order coefficients are not required. The behavior of the coefficients requires a highly elastic resonance near 1815 MeV and is consistent with the existence of an additional

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‡ Present Address: University of Maryland, Department of Physics, College Park, Md.

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

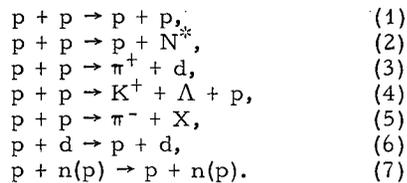
†† Present Address: Brookhaven National Laboratory, Upton, Long Island, New York.  
2. Richard L. Crollius, A Measurement of the Polarization of Sigma-Zero Hyperons Produced by Pi-Minus Mesons on Hydrogen Near 1.3 BeV/c (Ph. D. thesis), UCRL-16089, May 26, 1965.

enhancement near 1765. The 1765-MeV resonance, if it exists, is rather inelastic. Least-square fits of one or more Breit-Wigner resonance terms with constant backgrounds to the elastic and total cross sections and a qualitative analysis of the Legendre polynomial coefficients favor a  $J = 5/2$  assignment for the 1815-MeV resonance, although  $J = 3/2$  cannot be completely excluded. Details of these results were presented at the 1965 American Physical Society in Honolulu, and a Physical Review article is being prepared.

#### PROTON-PROTON AND PROTON-DEUTERON INTERACTIONS FROM 3 TO 7 GeV/c

Charles M. Ankenbrandt, Alan R. Clark, Bruce Cork, Tom Elioff, Leroy T. Kerth, and W. A. Wenzel

The analysis of our experimental data on proton-proton and proton-deuteron interactions is continuing. By use of the apparatus described in UCRL-14995,<sup>3</sup> differential cross sections or missing-mass spectra were measured between lab angles of 9 and 70 deg for the reactions



Preliminary results on the production angular distributions of Reaction (2) have been reported.<sup>4</sup> Corrections for variations in solid angle and in Cerenkov counter efficiency are being calculated.

#### $\pi$ - $\pi$ INTERACTIONS

Denis Keefe, Leroy T. Kerth, Carl M. Noble, John J. Thresher,<sup>†</sup> W. A. Wenzel, and T. G. Zipf<sup>††</sup>

A spark chamber momentum spectrometer was used to investigate the process  $\pi^- + p \rightarrow \pi^- + \pi^+ + n$  at incident momenta of 4, 3, and 2 BeV/c. The data have been completely measured, yielding  $\approx 1500$  low-momentum transfer events at each incident momentum.

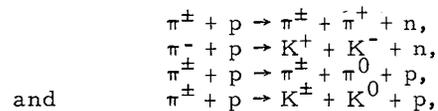
The diboson mass spectrum in the  $\rho$  region is found to be a strongly varying function of four-momentum transfer to the nucleon in the low region ( $< 9 \mu^2$ ). Structure is seen but the statistics are insufficient to establish the cause. Final-state interactions, competing isobaric processes, or another resonance in the  $\rho$  region may be involved.

Interpretation of the final data, including the above effects, is nearing completion, and a final report is being written for submission to the Physical Review.

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

Alan R. Clark, Bruce Cork, Tom Elioff, Denis Keefe, Leroy T. Kerth, and W. A. Wenzel

This experiment is to measure the diboson spectrum up to masses larger than that of the  $f^0$  (1250 MeV). The reactions to be studied include



with the incident pion momentum varying from 2 to 4.5 GeV/c. Several regions of particular interest are the  $K^+K^-$  spectrum in the vicinity of the  $f^0$  and the  $\pi^+\pi^-$  spectrum in the  $\rho$  region (700 to 800 MeV). Results from a previous experiment by this group showed significant structure in the dipion spectrum near the  $\rho$  mass. This experiment will increase considerably the statistics in this region, and also provide better measurement precision. The apparatus for this experiment is now under construction. The magnetic field for the large-volume magnet ( $M_5$ ) which will contain the spark chambers has been measured. A large-volume gas Cerenkov counter is being built, and testing of spark chambers is under way. A parasitic beam is now being used at the Bevatron to expedite the preliminary tests of the spark chambers as well as the associated electronics involved in the experiment. The experiment is scheduled to be begun in February 1966.

#### $\Sigma^\pm$ DECAYS

Alan R. Clark, Bruce Cork, Tom Elioff, Denis Keefe, Leroy T. Kerth, and W. A. Wenzel

The purpose of this experiment is to study the decay of  $\Sigma^\pm$ 's produced in the reaction  $\pi^\pm + p \rightarrow \Sigma^\pm + K^+$  at an incident momentum of 1.13 BeV/c. The processes to be studied include

3. C. M. Ankenbrandt, A. R. Clark, Bruce Cork, T. Elioff, L. T. Kerth, and W. A. Wenzel, Orthogonal Dispersion Spectrometer for Missing-Mass Spectra, UCRL-14995, May 1965.

4. T. Elioff, C. M. Ankenbrandt, A. R. Clark, Bruce Cork, L. T. Kerth, and W. A. Wenzel, Bull. Am. Phys. Soc. 10, 717 (1965).

- (a) Measurement of the decay parameter  $\alpha$ ,  $\beta$ , and  $\gamma$ , for  $\Sigma^\pm \rightarrow \pi^\pm + n$ .
- (b) Remeasurement of  $\alpha$  for  $\Sigma^+ \rightarrow \pi^0 + p$ , and accurate determination of  $\beta$  and  $\gamma$  for this mode.
- (c) Remeasurement of  $\alpha$  for  $\bar{p}$  for the above modes.
- (d) Measurement of the branching ratio for  $\Sigma^+ \rightarrow p + \gamma$ .
- (e) Measurement of the rare decay modes  $\Sigma^\pm \rightarrow \pi^\pm + n + \gamma$ , if background permits.

Detailed planning of the experiment is in progress. The experiment is not scheduled to start at the Bevatron before November 1966.

#### REPORTS AND PAPERS

##### Papers given orally

1. E. J. Lofgren, Design Study for the 200 BeV Proton Accelerator, invited paper for 1965 Meeting of American Physical Society at Honolulu, September 4, 1965.
2. D. Keefe, Experimental Areas and Facilities at the 200 BeV Accelerator, given at V International Conference on High Energy Accelerators at Frascati (Rome), Italy, September 9-16, 1965.

##### Papers published

3. W. W. Chupp, T. Elioff, and W. A. Wenzel, The Improved Bevatron and Its Performance at High Intensity (UCRL-16228, August 26, 1965) (to be published in Proceedings of V International Conference on High Energy Accelerators at Frascati, Italy).
4. C. M. Ankenbrandt, A. R. Clark, B. Cork, T. Elioff, L. T. Kerth, and W. A. Wenzel, Orthogonal Dispersion Spectrometer

- for Missing Mass Spectra, IEEE Trans. Nucl. Sci. NS 12 [8], 113 (1965).
5. D. Cutts, T. Elioff, and R. Steining, Muon Polarization and Energy Spectrum in  $K^+ \rightarrow \pi^0 \mu^+ \gamma$ , Phys. Rev. 138, B763 (1965).
  6. Denis Keefe, Experimental Areas and Facilities at the 200 BeV Accelerator (UCRL-16223, August 25, 1965) (to be published in Proceedings of V International Conference on High Energy Accelerators at Frascati, Italy).

##### Reports issued

7. Richard L. Crolis, A Measurement of the Polarization of Sigma Zero Hyperons Produced by Pi-Minus Mesons on Hydrogen Near 1.3 BeV/c (Ph. D. thesis), UCRL-16089, May 26, 1965.

##### Abstracts submitted

8. A. R. Clyde, Bruce Cork, D. Keefe, L. T. Kerth, W. M. Layson, and W. A. Wenzel, Proton-Proton Elastic Scattering (UCRL-16458 Abstract, October 15, 1965) (to be presented at December 20-22, 1965, meeting of American Physical Society at Los Angeles).
9. T. Elioff, C. Ankenbrandt, A. R. Clark, Bruce Cork, L. T. Kerth, and W. A. Wenzel, p-p Inelastic Scattering from 3-7 BeV/c, Bull. Am. Phys. Soc. II, 10, 717 (1965).
10. W. R. Holley, E. F. Beall, L. T. Kerth, D. Keefe, J. J. Thresher, C. L. Wang, and W. A. Wenzel,  $K^-$ -Proton Elastic Scattering from 700 to 1350 MeV/c, Bull. Am. Phys. Soc. II, 10, 679 (1965).
11. C. L. Wang, E. F. Beall, W. R. Holley, D. Keefe, L. T. Kerth, J. J. Thresher, and W. A. Wenzel, Polarization of Protons in  $K^-$ -p Elastic Scattering, Bull. Am. Phys. Soc. II, 10, 679 (1965).

PHYSICS RESEARCH

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

CHECK ON CPT INVARIANCE  
FROM  $\pi^+$  AND  $\pi^-$  LIFETIMESBrenton Stearns, Richard J. Kurz,  
Robert W. Kenney, Arthur J. Greenberg,  
Richard J. Eandi, David O. Caldwell,  
and David S. Ayres

The experimental program has been carried to the point of smooth data collection. The  $\pi^+$  and  $\pi^-$  beams are understood and appear to be adequate, and the experimental apparatus is all operating satisfactorily. Lifetime measurements are currently of accuracy within 3%. The ultimate accuracy in our present configuration is perhaps within 0.75%. Upon achieving this level, another kind of experimental arrangement will be considered if the experimental results so demand.

No careful measurement of the pion beam momenta has yet been made; however, magnetic spectrometer measurements of these momenta are scheduled for the next running period. Until these data are available, it is clearly premature to relate our results to existing measurements of the charged-pion lifetimes. More data will be collected, in completing this experiment, in order to make a meaningful statement about the equality of particle-antiparticle lifetimes.

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

Thomas B. Risser

This experiment is designed to measure the recoil neutron polarization in the region of the proposed  $P_{11}$  resonance at 550 MeV. This will be done for c.m. scattering angles from 100 to 150 deg (10 to 35 deg lab neutron).

All the equipment has been designed and most of the apparatus has been built. Since this experiment was postponed in favor of the  $K_S^0 \rightarrow 2\pi^0$  experiment, further construction has been temporarily suspended. The only major item not nearly finished is the large, cylindrical spark chamber. It is ready for assembly pending completion of tests on a model. These tests are under way.

PION-PROTON  
CHARGE-EXCHANGE EXPERIMENT

Charles B. Chiu and W. Bruce Richards

The Bevatron run for this experiment was completed at the end of October 1963. In

previous reports the purpose of this work has been described and an outline of the scanning of the film and the analysis of the data has been given.

During the period of this report the scanning and analysis have been completed as planned. Extensive discussion of the experiment and analysis, and the resulting total and differential cross sections for the reaction  $\pi^-p \rightarrow \pi^0n$ , are contained in a Ph. D. thesis.<sup>1</sup> Data on the total and differential cross sections for  $\pi^-p \rightarrow \eta n$  were summarized in a report presented at the September 1965 joint meeting of the American Physical Society and the Physical Society of Japan in Honolulu, Hawaii.<sup>2</sup> A Ph. D. thesis giving a more detailed description of these  $\eta$  cross sections is essentially completed.<sup>3</sup>

At the present time we are in the process of extracting from our data the total cross sections for the production of  $2\pi^0n$  and  $3\pi^0n$  final states. In the next few months our data will be combined with the data measured by our collaborators at the University of Hawaii, and the final results published.

DETERMINATION OF THE  
NEUTRON-NEUTRON SCATTERING LENGTH  
FROM THE REACTION  $H^3(d, He^3)2n$ Eugen Baumgartner,\* Homer E. Conzett,\*  
Edward Shield, and Rodolfo J. Slobodrian\*

We have measured cross sections,  $(d^2\sigma/d\Omega dE)$ , of  $He^3$  from the reaction  $H^3(d, He^3)2n$  at 32.7 and 40.4 MeV, for several laboratory-system angles between 6 and 25 deg. These spectra were obtained with very high statistics (15 000 events at 6 deg) and an energy resolution of 240 keV. In addition, cross sections for  $H^3$  from the reaction  $He^3(d, H^3)2p$  were measured at 30 MeV. In both cases, the shape of the spectra is dominated by the nucleon-nucleon forces appearing as final-state interactions. In the data analysis now in progress, we will extract both the

## \*Nuclear Chemistry

1. Charles B. Chiu, Pion-Proton Charge-Exchange Scattering, 500 to 1300 MeV (Ph. D. thesis), UCRL-16209, Nov. 1965.
2. W. Bruce Richards and Charles B. Chiu, Total and Differential Cross Sections for the Reaction  $\pi^-p \rightarrow \eta n$ , UCRL-16140, Sept. 1965.
3. W. Bruce Richards, Total and Differential Cross Sections for  $\pi^-p \rightarrow \eta n$  from Threshold to 1300 MeV (Ph. D. thesis), UCRL-16195, November 1965.

proton-proton and neutron-neutron scattering lengths from these mirror reactions, using the factored wave-function method.<sup>4,5</sup>

Within the limitations of the theory we expect to obtain an accurate determination of  $a_{nn}$ , with the determination of  $a_{pp}$  as a good empirical test of the validity of the theory for the above reactions.

#### POLARIZATION IN p- $\alpha$ SCATTERING BETWEEN 27 AND 63 MeV

Edmund Boschitz,\* Marc Chabre,\*  
Homer E. Conzett, Edward Shield,  
Rodolfo J. Slobodrian,\* and William F. Tivol

Polarizations in p-He<sup>4</sup> elastic scattering were measured at proton energies of 6.8, 34.2, 44.1, 54.8, and 63.3 MeV, by use of the polarized proton beam facility at the 88-inch cyclotron; the beam polarization,  $p_1$ , has been determined in previous experiments, and the polarization of the elastic p-He<sup>4</sup> scattering is

$$P(E, \theta) = \epsilon(E, \theta)/P_1,$$

where  $\epsilon(E, \theta)$  are the experimentally determined asymmetries.

This series of measurements, with other polarization data and cross sections, gives a set of experimental results at approximately 5-MeV intervals over the region of 10 to 63 MeV. A preliminary phase-shift analysis has been performed, and the predicted polarizations and experimental data are shown in the table below. (Data from the Rutherford Laboratory<sup>6</sup> are labeled RHEL.)

	C	Cr	Mo	V	Ni	Mn	Si
HY TUF	0.25	0.30	0.39	--	1.74	1.35	1.25
D6AC	0.26	1.14	0.99	0.02	0.54	0.70	0.22
5M21	0.19	0.48	2.93	--	3.02	0.49	0.36

#### DOUBLE CHARGE-EXCHANGE EXPERIMENT

Victor Perez-Mendez, Leon Kaufman,  
and Princeton Group

An experiment to detect  $\Delta T_z = 2$  analog states in neutron-rich nuclei by double charge-exchange scattering of pions was carried out

\*Nuclear Chemistry Division

4. A. B. Migdal, Soviet Physics JETP 1, 2 (1955).

5. K. M. Watson, Phys. Rev. 88, 1163 (1952).

6. M. K. Craddock, R. C. Hanna, L. P. Robertson, and B. W. Davies, Phys. Letters 5, 335 (1963).

jointly with a Princeton University group consisting of J. Solomon, T. Devlin, P. Boynton, and two other Princeton students. The theoretical cross sections for the production mechanism were worked out by G. E. Brown and S. Barshay (Princeton and Rutgers). The double charge-exchange reaction is  $\pi^\pm + {}_Z A \rightarrow {}_{Z\pm 2} A + \pi^\mp$ , and is identified by detecting a charged pion of opposite charge to the incident pion.

In this experiment a beam of  $\pi^+$  of incident energy  $210 \pm 3$  MeV was used, incident on targets of vanadium, zirconium, and lithium, for which cross sections had been calculated by Brown and Barshay. The final-state  $\pi^-$  and their momentum distributions were measured by a magnetic spectrometer with a Cerenkov gas counter to "anti out"  $e^-$ , which were a major source of background. Input and output directions of the  $\pi^-$  were identified by two pairs of spark chambers with magnetostrictive readout. A few hundred events on each of the three elements were detected, and a preliminary analysis indicates that the cross section for analog-state production is at least an order of magnitude smaller than predicted. An analysis of the data to understand the shape of the observed momentum distribution of the  $\pi^-$  from double charge-exchange events is under way.

#### HELIUM-FILLED WIDE-GAP CHAMBER PROJECT

Albert W. Stetz and Victor Perez-Mendez

Several prototype wide-gap chambers filled with helium have been assembled and tested successfully for track reproducibility with cosmic rays. Since we expect to use these chambers as analyzers of low-energy (20 to 100 MeV) neutrons and protons from  $\pi$ -nucleon interactions by the track produced by the recoils, we are now preparing to test a final-size chamber using medium-energy protons from the 184-inch cyclotron. Following this test run we propose to calibrate the analyzing power of helium for protons of energy  $E_p = 50$  to 100 MeV, where existing data are insufficient, and then to use the chamber in a charge-exchange  $\pi$ -nucleon experiment.

#### MAGNETOSTRICTIVE READOUT DEVELOPMENT FOR SPARK CHAMBERS

Victor Perez-Mendez, J. Pfab,<sup>†</sup>  
and F. Kirsten<sup>†</sup>

Four modular wire chambers for use in determining input and output directions of

<sup>†</sup>Electrical Engineering Research and Development Group

charged particles in a magnetic spectrometer were constructed. Each module consists of two gaps with four readout planes at 45 deg to each other in order to be able to read multiple spark events. The performance of these chambers was checked by an elastically scattered pion of known momentum and the accuracy of spark location found to be within less than 0.5 mm.

Various considerations on the design of the readout electronics have been studied, and prototypes of some of those have been assembled. These developments are described in UCID-2629, Aug. 1965.

#### SPARK CHAMBER PULSER

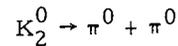
Sherwood I. Parker and Charles A. Rey

A compact, low-inductance spark-gap pulser of simple construction has been developed. The complete pulser measures  $6 \times 14 \times 1.6$  cm, and thus is thinner than the double-gap spark chamber which it drives, permitting both short, low-inductance connections and the reduction of the chamber load capacity through its subdivision into double gap units. The pulser capacity is more than 8000 pF. The rise time of the pulse in a  $1.5 \times 1.2$ -m  $\times$   $0.8$ -cm double-gap chamber is about 13 nsec.

#### POSITRON HELICITY IN THE DECAY $\mu^+ \rightarrow e^+ + \nu + \bar{\nu}$

Sherwood I. Parker and Charles A. Rey

Measurement of spark chamber pictures for this experiment is continuing. All together, 600 000 pictures were taken, of which one-third are of Bhabba scattering of the positron in a highly magnetized foil and in which both the positron and electron enter the fiducial regions of downstream spark chambers. Approximately 200 000 pictures have been measured to date.



Robert Cence, D. Cheng, C. Caldwell,  
R. Eandi, A. C. Helmholz, B. Jones,  
Robert W. Kenney, W. Oliver,  
Sherwood I. Parker, Victor Perez-Mendez,  
and Charles A. Rey

Design and construction of equipment is continuing for the measurement of the branching ratio for  $K_2^0 \rightarrow \pi^0 + \pi^0$ . Knowledge of its value is important for a full understanding of the CP-violating process responsible for the observed decay  $K_2^{01} \rightarrow \pi^+ + \pi^-$ . The experiment will use nearly monoenergetic  $K_2^{01}$ 's produced by a beam of  $1.00 \pm 0.04$ -BeV/c  $\pi^-$  mesons incident on a 1.2-m  $H_2$  target. A magnetic field will sweep out charged particles and a lead filter will remove  $\gamma$ 's from the beam. The  $K_2^{01}$ 's will pass through a collimator, through a four-sided tunnel made of scintillator-lead-Lucite anticounters, and enter a decay volume surrounded on five of its six sides by anticounters followed by an Al plate spark chamber module and Al-Pb-Al plate spark chamber modules with a thickness of seven radiation lengths. Only 3% of the main background process  $K_2^0 \rightarrow 3\pi^0$  will produce events with only four showers, and less than 3% of those should be mistaken for  $K_2^0 \rightarrow 2\pi^0$  after a kinematical analysis is made. Cerenkov counters will be used for triggering to discriminate against neutron interactions.

The current status is as follows:

- (a) The pion beam design has been completed. An intensity of about  $7 \times 10^6 \pi^-$  per  $10^{12}$  protons is expected at the  $H_2$  target.
- (b) Monte Carlo calculations have been run to estimate true and background event rates. More detailed calculations are now being developed.
- (c) The necessary spark chambers, supporting frames, and scintillators are now being built. Testing is under way on sample  $1.2 \times 1.5$ -m lead plate chambers.
- (d) Development work on Cerenkov trigger counters is proceeding satisfactorily.

PHYSICS RESEARCH

Wilson M. Powell and Robert W. Birge in charge

K<sup>-</sup>p AND K<sup>-</sup>d INTERACTIONS  
IN THE MOMENTUM INTERVAL  
825 TO 1415 MeV/c

Robert B. Bell, Robert W. Birge,  
Robert P. Ely, George E. Kalmus,  
Anne Kernan, James Louis, Wilson M. Powell,  
Robert T. Pu, Jack Sahouria,  
and Wesley M. Smart

All together, 195 000 pictures of K<sup>-</sup>p and 215 000 of K<sup>-</sup>d interactions have been taken in the Lawrence Radiation Laboratory 25-inch bubble chamber. We are making a detailed study of the K<sup>-</sup>-nucleon interaction in this momentum interval, with special emphasis on the determination of the quantum numbers of Y<sub>1</sub><sup>\*</sup>(1765) and Y<sub>0</sub><sup>\*</sup>(1815).

A total of 26 000 events has been measured on the FSD, and 29 000 events with Franckensteins and digitized microscopes. An event having a track less than 5 mm long, such as a Σ hyperon or a spectator proton, cannot yet be measured on the FSD.

The following reactions are being studied:

<u>Reaction</u>	<u>Number of events</u>
K <sup>-</sup> p → $\bar{K}^0_n$	(3200)
Λ π <sup>0</sup>	(3400)
Λ π <sup>+</sup> π <sup>-</sup>	(3500)
Λ π <sup>+</sup> π <sup>-</sup> π <sup>0</sup>	(450)
Σ <sup>+</sup> π <sup>-</sup>	(4200)
Σ <sup>-</sup> π <sup>+</sup>	(2000)
Σ <sup>+</sup> π <sup>-</sup> π <sup>0</sup>	(1500)
Σ <sup>-</sup> π <sup>+</sup> π <sup>0</sup>	(500)
K <sup>-</sup> n → K <sup>-</sup> n	(500)
Λ π <sup>-</sup>	(3800)
Λ π <sup>-</sup> π <sup>0</sup>	(3400)
Σ <sup>-</sup> π <sup>-</sup> π <sup>+</sup>	(2000)
Σ <sup>+</sup> π <sup>-</sup> π <sup>-</sup>	(2000)
K <sup>-</sup> d → K <sup>-</sup> d	(290)

The Reaction K<sup>-</sup>p →  $\bar{K}^0_n$

The total and differential cross sections have been measured at all momenta. The total cross section shows a pronounced resonance-like peak at 1815 MeV with a full width at half maximum of 60 MeV. The angular distributions can be fitted with a Legendre polynomial expansion up to fifth order. The sharp peak in the fourth-order coefficient at 1815 MeV confirms the J = 5/2 spin assignment for Y<sub>0</sub><sup>\*</sup>(1815). The behavior of the fifth-order coefficient indicates the presence of two J = 5/2 amplitudes of opposite parity in the c. m. energy interval 1760 to 1815 MeV.

Parity of Y<sub>0</sub><sup>\*</sup>(1815)

A study of the angular distribution of Y<sub>1</sub><sup>\*</sup>(1385) in the reactions K<sup>-</sup>p → Y<sub>1</sub><sup>\*</sup>(1385) + π<sup>+</sup> and K<sup>-</sup>n → Y<sub>1</sub><sup>\*</sup>(1385) + π<sup>0</sup> showed that the parity of Y<sub>0</sub><sup>\*</sup>(1815) is positive. A report on the parity determination was presented at the Athens, Ohio, Conference in June 1965 (Conference Proceedings, p. 296).

Parity of Y<sub>1</sub><sup>\*</sup>(1765)

The angular distribution of Y<sub>0</sub><sup>\*</sup>(1520), produced in the reactions K<sup>-</sup>n → Y<sub>0</sub><sup>\*</sup>(1520) + π<sup>-</sup> → Σ<sup>-</sup>π<sup>+</sup>π<sup>-</sup>, indicates J<sup>P</sup> = 5/2<sup>0</sup> for Y<sub>1</sub><sup>\*</sup>(1765). This work is described by Robert B. Bell, Robert W. Birge, Y. L. Pan, and Robert T. Pu, Spin-Parity Determination of Y<sub>1</sub><sup>\*</sup>(1765), UCRL-16451, Oct. 1965.

The Reactions K<sup>-</sup>n → Λπ<sup>-</sup> and K<sup>-</sup>p → Λπ<sup>0</sup>

The total cross section, angular distribution, and Λ polarization have been studied over the momentum interval 8500 to 1100 MeV/c. The total cross section for this pure I = 1 reaction does not show a pronounced bump at 1760 MeV. The angular distributions can be fitted with a Legendre polynomial expansion up to third order, except in the c. m. energy interval 1750 to 1780 MeV, where a fourth-order fit is required. The differential cross sections and the Λ polarization give strong evidence for the presence of a J<sup>P</sup> = 5/2<sup>-</sup> amplitude in the c. m. energy region of 1760 MeV. The Λ is strongly polarized in the backward hemisphere between 1720 and 1780 MeV c. m. energy.

The Reaction K<sup>-</sup>p → Σ<sup>+</sup>π<sup>-</sup>

The angular distributions and polarization of the Σ<sup>+</sup> have been studied at all momenta. The angular distributions show the presence of J = 5/2 amplitudes; the Σ<sup>+</sup> has a large polarization which varies rapidly with c. m. energy and production angle.

K<sup>-</sup>d and K<sup>-</sup>n Elastic Scattering

A study of the total and differential cross sections in these reactions has been initiated.

EXPERIMENTAL STUDY OF K<sub>e4</sub> DECAY

Powell-Birge Group

The group is collaborating with University College, London, and the University

of Wisconsin on a new experiment to collect a larger number of events. Approximately 300 000 pictures have been taken in the heavy-liquid chamber at CERN and an equal number is yet to come.

#### 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 530 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  $K_{e3}^+$  decay are overdetermined when pair conversion of both  $\gamma$  rays from  $\pi^0$  decay occurs.

We are using the data to determine the energy dependence of the form factor  $f_+$  and to obtain upper limits on the amount of scalar and tensor that might be present.

A preliminary report on this work was submitted to the 1964 International Conference on High Energy Physics, Dubna (UCRL-11553). The film is being check-scanned and the analysis of the data continues.

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

#### THE REACTION $d + n \rightarrow d + p + \pi^-$ IN dd COLLISIONS AT 3.64 BeV/c

George Gidal, Anne Kernan, and Sedong Kim

The Brookhaven National Laboratory 20-inch bubble chamber, filled with deuterium, was exposed to a 3.64-BeV/c separated deuteron beam at the AGS. The film contains approximately 200 interactions of the type  $dd \rightarrow dp\pi^-p_s$ , where  $p_s$  indicates a spectator proton in either the beam or the target deuteron. The reaction is characterized by (a) small four-momentum transfer to the deuteron [ $\Delta^2 = 0.14$  (BeV/c)<sup>2</sup>], (b) peaking of the  $(d\pi^-)$  invariant mass distribution around 2.17 BeV, and (c) strong forward peaking of the distribution in the scattering angle of the deuteron in the  $(d\pi^-)$  rest system. Similar effects have been observed in the reactions

$\pi^- d \rightarrow \pi^- \rho^0 d$  at 3.7 BeV/c,<sup>1</sup> and  $K^+ d \rightarrow K^*0(891) \pi^+ d$  at 2.3 BeV/c.<sup>2</sup> A study of the reaction mechanism is in progress.

#### dd ELASTIC SCATTERING AT 3.64 BeV/c

George Gidal, Anne Kernan, and Sedong Kim

The above exposure contains approximately 500 dd elastic scatterings. The total and the differential cross sections are being measured.

#### MEASUREMENT OF $K_{\mu 3}^+$ DECAY PARAMETERS

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

$K^+$  mesons were stopped in  $C_3F_8$  in the Lawrence Radiation Laboratory 30-inch heavy-liquid bubble chamber, and have been used to study the properties of the decay mode  $K^+ \rightarrow \pi^0 + \mu^+ + \nu$ . The properties studied were the  $\mu^+$  and  $\pi^0$  energy spectra,  $\mu^+$  longitudinal polarization,  $\mu^+$  total polarization, and  $K_{\mu 3}^+/K_{e 3}^+$  branching ratio. The data are consistent with the universal V-A theory, with time-reversal invariance and  $\mu$ -e universality. Using the usual form-factor phenomenological expression for the strangeness-changing vector current, we obtain

$$\text{Re } \xi = +0.34 \begin{matrix} +0.26 \\ -0.42 \end{matrix},$$

$$\text{Im } \xi = +0.69 \begin{matrix} +0.85 \\ -1.0 \end{matrix},$$

$$\lambda_+ = 0.00 \pm 0.05,$$

$$f_+(K_{\mu 3})/f_+(K_{e 3}) = 1.01 \pm 0.05.$$

$\text{Im } \xi$  should vanish by time-reversal invariance and  $f_+(K_{\mu 3})/f_+(K_{e 3})$  should be unity if  $\mu$ -e universality holds.

This work was done in collaboration with the University of Wisconsin and with Sergio Natali and Matteo Villani at the Università di Bari, Italy.

1. M. A. Abolins, D. D. Carmony, R. L. Lander, and Ng-h Xuong, Phys. Rev. Letters 15, 125 (1965).
2. I. Butterworth, J. Brown, G. Goldhaber, S. Goldhaber, A. Hirata, J. Kadyk, and G. Trilling, Phys. Rev. Letters 15, 500 (1965).

## DATA REDUCTION

Robert W. Birge and P. Wesley Weber

With a total of 24 (full-time equivalent) visual measurements personnel, the following data reduction was accomplished in the past six months:

Scanning			
<u>Experiment</u>	<u>Bubble Chamber</u>	<u>Beam</u>	<u>Number of Frames</u>
Conventional system			
29	20-inch deuterium (Brookhaven)	3.69-BeV/c deuteron	30 264
32	25-inch hydrogen	850 to 1150-MeV/c K <sup>-</sup>	345 565
34	25-inch deuterium	850 to 1150-MeV/c K <sup>-</sup>	521 243
35	1.1-Meter CERN heavy liquid (C <sub>2</sub> F <sub>5</sub> Cl)	Stopping K <sup>+</sup>	530
		Subtotal	<u>897 602</u>
FSD system			
32	25-inch hydrogen	850 to 1150-MeV/c K <sup>-</sup>	80 783
34	25-inch deuterium	850 to 1150-MeV/c K <sup>-</sup>	2 895
		Subtotal	<u>83 678</u>
		<u>Total</u>	<u>981 280</u>

Measuring				
<u>Equipment</u>	<u>Measuring hours</u>	<u>Number of events</u>	<u>Events per measuring hour<sup>a</sup></u>	<u>Measuring Hours per 4032 hours</u>
Microscope C	2589.7	11 572	4.5	0.59
Microscope E	2390.3	10 050	4.2	0.55
MP-1C	<u>2746.3</u>	<u>14 222</u>	<u>5.2</u>	<u>0.63</u>
<u>Total</u>	7726.3	35 844	4.6	0.59

<sup>a</sup>Note that we are now tabulating "events" rather than "vertices." Assuming two vertices per event, we have increased our absolute rate 65% over the previous 6 months because of the inauguration of a personnel rotation system. That is, personnel are measuring for 2-hour periods only, then scanning for 2 hours, thus eliminating a great deal of the fatigue factor inherent in measuring for longer periods. The quoted measuring rate is based on the measurement of all tracks in three views.

PHYSICS RESEARCH

Emilio Segrè and Owen Chamberlain in charge

PROTON-PROTON INTERACTIONS  
AT 6 GeV/cW. Chinowsky, Robert R. Kinsey,  
Stanley L. Klein, Mark A. Mandelkern,  
Kwok M. Ong, and Jonas Schultz

The experiment to study p-p interactions in the 72-inch bubble chamber continues. A total of  $\approx 235\,000$  photographs was obtained during the operation in April and May 1965. At present, running at the Bevatron is again in progress and will continue through December 1965. It is expected that we will double the number of pictures taken. About half the pictures have now been scanned for strange-particle production events. Preliminary results, based on measurements of 15% of the data, indicate a  $V^0$  production cross section of  $\approx 250$   $\mu\text{b}$ , with the  $\Lambda^0/K^0$  production  $\approx 2/1$ . The states  $\Lambda^0 K^+$  and  $\Sigma^0 K^+$  occur with roughly equal abundance. No evidence has yet been found for an enhancement in the  $\Lambda^0 p$  or  $\Sigma^0 p$  state at low Q values. Some production of  $N^*(1688)$ , identified by the occurrence of the decay mode  $N^* \rightarrow \Lambda^0 K^+$ , has been observed. These results are of course still tentative. Analysis of the hyperon and K-meson production is continuing. Events with two prongs and four prongs are being measured with the FSD at a rate of  $\approx 1000$  per week. Study of the quality of the measurements has not enabled us to make conclusions, and so no results from these measurements can yet be reported with reliability.

TEST OF TIME-REVERSAL INVARIANCE  
IN  $K^+ \rightarrow \pi^0 + \mu^+ + \nu$ David Cutts, Martin Deutsch,  
Rae F. Stiening, and Clyde E. Wiegand

A separated  $K^+$  beam has been installed and tested. The beam yields approximately 1000 stopping  $K^+$  per Bevatron pulse with  $5 \times 10^{11}$  protons incident on a 2-in. -thick uranium target. Sixty fast particles pass through the final focus for every stopping  $K^+$ . The spark chambers for the detection of the K decay products are now being installed at the final focus in the K beam.

INTRINSIC RELATIVE PARITY  
OF THE K- $\Sigma$ -N SYSTEMByron D. Dieterle, John F. Arens,  
Owen Chamberlain, Paul D. Grannis,  
Michel J. Hansroul, Leland E. Holloway,  
Claiborne H. Johnson, Claude H. Schultz,  
Gilbert Shapiro, Herbert M. Steiner,  
and David M. Weldon

The experiment, completed in January of 1965, consisted of scattering  $\pi^+$  mesons of 1150 MeV/c from the protons of a polarized hydrogen target, and measuring the asymmetry in the production of the final state  $K^+ + \Sigma^+$ . The algebraic sign of this asymmetry directly gives the K- $\Sigma$ -N parity.

A scan of the 50 000 spark chamber pictures taken in the course of the experiment shows about 13 000 of the frames to be measurable. Of these 13 000 pictures about 11 000 have been measured on the SCAMP system and 5500 have been subjected to preliminary analysis on the 7094.

The computer kinematic program separates 1275  $K^+$ -hyperon events originating from the polarized target, and of these 200 are estimated to be from the polarized hydrogen in the target. The remainder are events from the heavy elements in the target:

$$\pi^+ p_{\text{bound}} \rightarrow K^+ \Sigma, \quad (1)$$

$$\pi^+ n_{\text{bound}} \rightarrow K^+ \Sigma^0, \quad (2)$$

$$\pi^+ n_{\text{bound}} \rightarrow K^+ \Lambda. \quad (3)$$

In order to obtain a better estimate of the background a Monte Carlo program is in progress.

With the completion of the remaining 60% of the data and a good background subtraction, a measurement of  $\Sigma^+$  polarization as well as the intrinsic K- $\Sigma$ -N parity should be possible.

POLARIZATION OF THE  $\Sigma^-$  IN  
THE PROCESS  $\pi^- + p \rightarrow K^+ + \Sigma^-$ David M. Weldon, John F. Arens,  
Owen Chamberlain, Byron D. Dieterle,  
Paul D. Grannis, Michel J. Hansroul,  
Leland E. Holloway, Claiborne H. Johnson,  
Claude H. Schultz, Gilbert Shapiro,  
and Herbert M. Steiner

Analysis is under way on a spark chamber experiment completed in March to measure the polarization of  $\Sigma^-$  produced by an 1150-MeV/c  $\pi^-$  beam incident on the Berkeley polarized proton target. Polarization of the  $\Sigma^-$  can be measured directly only with a polarized target, since the  $\Sigma^-$  decay asymmetry is small and does not reveal the polarization of the  $\Sigma^-$ . From the spark chamber film selected to be scanned (7000 pictures), 1300 pictures are to be measured and approximately 100 pictures are expected to correspond to free

proton events. All the spark chamber film has been scanned and 600 events have been measured.

POLARIZATION IN  
 $\pi^-p$  ELASTIC SCATTERING  
(250 TO 400 MeV)

John F. Arens, Owen Chamberlain,  
Helmut Dost, Michel J. Hansroul,  
Leland E. Holloway, Claiborne H. Johnson,  
Claude H. Schultz, Gilbert Shapiro,  
Herbert M. Steiner, and David M. Weldon

The polarization in elastic scattering of negative pions on protons is being studied. The experiment consists in observing the asymmetry of the scattering when the pions are scattered on a polarized proton target. It is well known that the asymmetry measurement actually being used is equivalent to a polarization measurement, once the assumption of time-reversal invariance is made.

The incident pions were produced at an internal target in the 184-inch cyclotron. In this experiment the pion kinetic energy was 250, 310, 350, or 400 MeV. Elastic scattering events were detected in the presence of a large background from heavy elements present in the polarized target by requiring that the kinematics of the two outgoing particles (pion and recoil proton) correspond to that of elastic scattering on a free proton. In essence, each event included was required to be coplanar with the beam and to have the right relationship between the laboratory-system scattering angles for elastic pion-proton scattering. Three rectangular arrays of counters were used, each consisting of two hodoscopes at 90 deg with respect to each other, so that many angles of scattering could be observed simultaneously. A small computer (PDP-5) was used to handle the data, write the details of each event on magnetic tape, and provide summary information on an oscilloscope display. The data from the run at the cyclotron are now being reduced. It is hoped that final results will be available within a few months.

POLARIZATION IN  
PION-PROTON ELASTIC SCATTERING  
(500 MeV TO 3.5 GeV)

Michel J. Hansroul, John E. Brolley,  
Owen Chamberlain, William Gorn,  
Paul D. Grannis, Leland E. Holloway,  
Claiborne H. Johnson, Charles C. Morehouse,  
Michael A. Paciotti, Herbert M. Steiner,  
Peter R. Robrish, Stephen Rock,  
and Luc Valentin

By a procedure very similar to that already used in a similar experiment at the

184-inch cyclotron, an experiment is being performed at the Bevatron to extend the polarization measurements to a higher energy region. As in the previous experiment, we are observing the asymmetry in scattering of pions by a polarized proton target. The kinematic relationships derivable from conservation of energy and momentum are used to distinguish elastic scattering on free protons from inelastic scattering and from scattering on the heavy elements in the target material, which is  $\text{La}_2\text{Mg}_3(\text{NO}_3)_{12} \cdot 24\text{H}_2\text{O}$ .

To allow separating the desired events from unwanted background, we use a rather elaborate arrangement involving some 120 counters. A small computer is again used to summarize preliminary results, display summary information on an oscilloscope, and record each event on magnetic tape for later more sophisticated analysis. The experiment is presently in progress at the Bevatron.

RADIATIVE PION DECAY

Peter K. Kijewski, Melvin K. Simmons,  
and Clyde E. Wiegand

An experiment to observe the decay  $\pi^+ \rightarrow \mu^+ + \nu + \gamma$  has progressed to the stage of yielding about 20 events per hour, and to date a few hundred decays have been recorded. In the experiment positive pions are stopped in a plastic scintillation counter and the decay chain  $\pi^+ \rightarrow \mu^+ + \nu + \gamma$ ;  $\mu^+ \rightarrow e^+ + \bar{\nu} + \nu$  is observed. The  $\gamma$  rays are detected by a NaI(Tl) counter, and all pulses are recorded on film via oscilloscopes. To help depress background only those decays are recorded in which the muons have less than about 3.5 MeV kinetic energy.

The extent to which the experiment will be pursued depends upon efficiency calibrations that are in progress.

CAPTURE OF PIONS  
AND  $\pi$ -MESIC ATOM FORMATION

Poh-shien Young, Donald C. Girvin,  
and Emilio Segrè

We have started, in collaboration with David Jenkins and others of the Crowe Group, an investigation of the capture probability of  $\pi$  mesons in the nuclei of several compounds by examining the emitted x rays.

The problem has ramifications in solid-state physics because the capture probability depends on the potential seen by the pion in the solid. In particular, we are investigating the effect of the alteration, produced by chemical binding, of the outer region of the atoms.

PHYSICS RESEARCH

Howard A. Shugart in charge

## ATOMIC BEAM GROUP

The systematic measurement of various atomic and nuclear properties continues as the primary goal of the Atomic Beam Group.

The techniques employed in this research include a variety of optical pumping methods as well as various atomic-beam methods. The properties measured on free radioactive atoms in a beam include nuclear spins, nuclear magnetic dipole and electric quadrupole moments, atomic hyperfine structures, hyperfine-structure anomalies, electronic angular momenta, and  $g_J$  factors. The advantages of beam techniques in obtaining these quantities rest in their conceptual simplicity and sensitivity and in the ease of interpretation of results. The measurements comprise important test information for theories of the nuclear ground state. In addition, information on the electronic structure of atoms both from beam experiments and from optical pumping experiments is useful in evaluating theories of atomic structure.

The activity of the group can be indicated by an enumeration of papers that have been published or issued during the period of this report.

1. T. Hadeishi, O. A. McHarris, and W. A. Nierenberg, Radiofrequency Resonance of the Metastable State ( $2^2P_{3/2}$ ,  $3^2S_{1/2}$ )<sub>2</sub> of Neon Produced and Aligned by Electron Impact, Phys. Rev. 138, A983 (1965).
2. T. Hadeishi and W. A. Nierenberg, Direct Observation of Quantum Beats Due to Coherent Excitation of Nondegenerate Excited States by Electron Impact, UCRL-16048, April 8, 1965.
3. R. Marrus and J. Yellin, Optical Pumping Transients in Rubidium-87 and Application to Disorientation Cross Sections (UCRL-16065, June 1965), Phys. Rev. (to be published).
4. Hyatt McDonald Gibbs, Total Spin-Exchange Cross Sections for Alkali Atoms from Optical Pumping Experiments (Ph. D. Thesis), UCRL-16034, March 12, 1965.
5. Joseph Yellin, Study of Optical Pumping Transients in Rubidium-87 and Application to Disorientation Cross Sections (Ph. D. Thesis), UCRL-16241, July 9, 1965.
6. R. D. Worley, V. J. Ehlers, W. A. Nierenberg, and H. A. Shugart, Hyperfine Structure Separation, Nuclear Magnetic Moment, and Hyperfine Structure Anomaly of Cesium-131, UCRL-12365, July 6, 1965.
7. H. Gibbs, Importance of Nuclear-Spin Effects in Extracting Alkali Spin-Exchange Cross Sections from Zeeman Optical Pumping Signals, Phys. Rev. 139, A1374 (1965).
8. Barbara M. Dodsworth and Howard A. Shugart, Nuclear Spin, Hyperfine Structure, and Magnetic Moment Investigations on  $^{61}\text{Cu}$ ,  $^{62}\text{Cu}$ , and  $^{64}\text{Cu}$ , (UCRL-16327, August 5, 1965), submitted to Phys. Rev.
9. Erol Aygün, Vernon J. Ehlers, Adnan Saplakoglu, and Howard A. Shugart, Electronic  $g_J$  Factor of Sodium, Bull. Am. Phys. Soc. 10, 691 (1965) (UCRL-16144 Abst., May 1965).
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12. Tetsuo Hadeishi, Chung-Heng Liu, and William A. Nierenberg, Orientation of the  $^3P_2$  Metastable State of Ar by "Exchange" Collision with Optically Pumped Cs Atoms, Bull. Am. Phys. Soc. 10, 691 (1965) (UCRL-16145 Abst., May 1965).
13. Tetsuo Hadeishi, Direct Observation of Quantum Beats Due to Coherent Excitation of Nondegenerate Excited States by Pulsed Electron Impact, Bull. Am. Phys. Soc. 10, 692 (1965) (UCRL-16146 Abst., May 1965).
14. H. Gibbs and R. J. Hull, ( $\text{Rb}^{87}$ - $\text{Rb}^{85}$ ) and ( $\text{Rb}^{87}$ - $\text{Cs}^{133}$ ) Spin-Exchange Cross Sections, Bull. Am. Phys. Soc. 10, 704 (1965) (UCRL-16129 Abst., May 1965).
15. R. J. Hull and L. C. Bradley, III, Measurement of Absorption Line Profiles with a Fabry-Perot Interferometer, UCRL-16262 Abst., Sept. 1965 (for Am. Opt. Soc., Philadelphia, Oct. 6-12, 1965).
16. Yau Wa Chan, Vernon J. Ehlers, and William A. Nierenberg, The Nuclear Spin and Magnetic-Dipole Moment of 39-min Gold-190, UCRL-16248, July 7, 1965.

PHYSICS RESEARCH

George H. Trilling and Gerson Goldhaber in charge

The experimenters involved in this work are Roger W. Bland, Michael G. Bowler, John L. Brown, Ian Butterworth, Jan W. Dash, Bob Del Vecchio, Chu-Min Fu, Gerson Goldhaber, Sulamith Goldhaber, Allan A. Hirata, John A. Kadyk, J. McNaughton, Bertram M. Schwarzschild, Victor H. Seeger, Benjamin C. Shen, J. Swihart, and George H. Trilling.

$K^+d$  INTERACTION AT 2.3 GeV/c

The study of  $K^+d$  interactions at 2.3 GeV/c described in the preceding semiannual report has been continued.

An analysis of 275 events of the type  $K^+d \rightarrow K^0pp$  has permitted a study of  $K^+n$  charge-exchange scattering. A large real component to the forward scattering amplitude is obtained.<sup>1</sup> This is in contrast to  $K^-p$  charge exchange, which in the high energy region has a predominantly imaginary forward amplitude. On the basis of a Regge model of KN scattering, which for charge exchange invokes only  $\rho$  and  $A_2$  trajectories, Phillips and Rarita<sup>2</sup> have predicted such behavior of  $K^+n$  and  $K^-p$  charge exchange.

The marked angular correlations between the decay angular distributions of the  $N^*(1236)$  and of the vector resonance observed<sup>3</sup> in  $\pi^+p \rightarrow N^*\rho^0$  have also been observed in  $K^+p \rightarrow N^*K^*\rho^0$  at 1.96 and 2.3 BeV/c, showing that the effect is not a consequence of Bose statistics but of final-state interactions.<sup>4</sup> The correlation is most marked between  $\cos \alpha_{N^*}$  and  $\cos \alpha_v$ , where  $\alpha_{N^*}$  is the angle between incident and scattered proton in the  $N^*$  rest system and  $\alpha_v$  that between incident and scattered positive meson in the  $\rho^0$  or  $K^*\rho^0$  rest system. For  $0.4 \leq \cos \alpha_v \leq 1.0$ ,  $\cos \alpha_{N^*}$  shows approximately the  $1+3 \cos \alpha_{N^*}$  distribution expected for the alignment produced by a pure pseudoscalar meson-exchange model; for  $-1.0 \leq \cos \alpha_v \leq -0.4$  the decay of the  $N^*$  is more nearly isotropic.

1. I. Butterworth, J. L. Brown, G. Goldhaber, S. Goldhaber, A. A. Hirata, J. A. Kadyk, B. M. Schwarzschild, and G. H. Trilling, Phys. Rev. Letters 15, 734 (1965).
2. R. J. N. Phillips and W. Rarita, Phys. Rev. 139, B1336 (1965).
3. Gerson Goldhaber, Lecture at the Conference on Particle and High Energy Physics, Boulder, Colorado, 1964.
4. G. Goldhaber, J. L. Brown, I. Butterworth, S. Goldhaber, A. A. Hirata, J. A. Kadyk, B. C. Shen, and G. H. Trilling, Phys. Letters 18, 76 (1965).

STUDY OF THE REACTION  
 $K^+ + p \rightarrow K + N + p$   
BETWEEN 0.86 AND 1.58 GeV/c

Some 8000 events of the types

$$K^+p \rightarrow K^0p\pi^+, \quad (1)$$

$$K^+p \rightarrow K^+p\pi^0, \quad (2)$$

and  $K^+p \rightarrow K^+n\pi^+ \quad (3)$

obtained with the LRL 25-inch bubble chamber have been analyzed. All three reactions were studied at incident momenta of 0.86, 0.96, and 1.20 GeV/c, and Reaction (1) was also studied at 1.36 and 1.58 GeV/c. The  $N^*(1236)$  is produced copiously at all momenta, and exhibits decay angular distributions in reasonable agreement with the  $\rho$ -exchange model with magnetic dipole coupling at the  $p\rho N^*$  vertex. The observed production angular distributions also agree well with this model up to 960 MeV/c, but at the higher momenta the characteristic forward collimation and reduction of the cross section relative to the predictions of the exchange model are observed. Substantial  $K^*(891)$  production is observed at the higher three momenta and, although 0.86 and 0.96 GeV/c are below the  $K^*$  threshold, some  $K^*$  production occurs at both these momenta through the low-mass tail of the resonance. At 1.2 GeV/c there is evidence for constructive interference between the  $N^*$  and  $K^*$  amplitudes in the overlap region.

STUDY OF  $K_2^0$  DECAYS  
AND INTERACTIONS

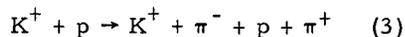
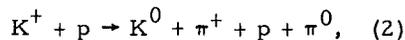
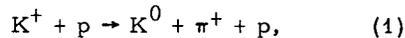
A new experiment in the 25-inch hydrogen bubble chamber was concluded at the end of May. This experiment, which was designed to study the decays and interactions of the long-lived  $K_2^0$  meson, ran for 2 months, and collected 0.7 million pictures. Throughout the experiment, the bubble chamber operated in the double-pulse mode, i.e., two separate expansions and beam spills occurred during each Bevatron cycle, thus doubling the usual picture rate. A  $K_2^0$  event was obtained at the rate of once in every 15 pictures.

Analysis of the experiment is currently

in progress. One rather immediate result concerns the low-energy phase shifts in the strangeness = -1 system. Until recently an ambiguity has existed in the solution for these phase shifts in  $K^-p$  experiments, where a mixture of  $T = 0$  and  $T = 1$  states exists. In this experiment,  $K^0p$  interactions are observed, which are in a pure  $T = 1$  state, and the ambiguity is resolved with a relatively small number of events. Of the two ambiguous  $K^-p$  solutions, only one is compatible with the  $K^0p$  interactions, and this one corresponds to the model of Dalitz and Tuan, which would explain the  $Y^*(1405)$  resonance as a  $\bar{K}N$  bound state.

#### $K^+p$ INTERACTIONS AT 4.6 GeV/c

An exposure of the Brookhaven National Laboratory 80-inch hydrogen bubble chamber to a 4.6-GeV/c separated  $K^+$  beam was carried out, and 45 000 photographs were taken. The analysis of these pictures has been initiated. The following reactions have so far been studied:



by means of both FSD and Franckenstein measurements. The statistics on Reactions (1), (2), and (3) obtained to date are 171, 288, and 550 events respectively, representing between 28% and 40% of the film. From these data the following preliminary conclusions can be drawn:

(i) In the four-body final states, double resonance production  $N^*(1236) K^*(1400)$  is important. Furthermore, the  $K\pi$  scattering angle distribution for  $K^*(1400)$  is consistent with the form  $[Y_2^0]^2$  expected for an aligned  $2^+$  meson produced by pion exchange.

(ii)  $K^*(1400)$  production appears significant in all three channels.

(iii) A  $K^*(890) \pi$  enhancement at  $\approx 1320$  MeV, similar to the one reported by Almeida et al.,<sup>5</sup> is observed. If this enhancement is treated as a kinematic consequence of  $K^*(890) \pi p$  production by pion exchange, the behavior of the  $\pi p$  scattering angle is suggestive of diffraction scattering. However, any adequate study of  $K^*$  alignment for these events must await increased statistics.

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5. S. P. Almeida, H. W. Atherton, T. A. Byer, P. J. Dornan, A. G. Forson, J. H. Scharenguivel, D. A. Sendall, and B. A. Westwood, Phys. Letters 16, 184 (1965).

DATA HANDLING

Howard S. White in charge

## COMPUTER PROGRAM DEVELOPMENT

HAZE

Error sources in the HAZE system were enumerated, and the main HAZE program (420) was modified to place error codes on the output library corresponding to the appropriate source of event rejection. These sources are:

- A. For view rejection:
  1. Scanner error or trouble with the reduction of scan information.
  2. Measuring--improper film positioning by FSD.
  3. Measuring--other hardware malfunction.
- B. For track rejection:
  1. Scanner error or trouble with the reduction of scan information.
  2. Filtering problems.
  3. Failure of the track to be reconstructed properly.

Studies have been begun which will systematically reduce frequently occurring errors by modifying measurement strategy.

Work was begun on a heuristic technique whereby transient hardware failures can be detected and the event remeasured immediately. This will substantially improve the event-measurement efficiency.

An improved ionization-measurement algorithm was designed and implemented. Studies have demonstrated that reliable ionization measurements can be made by the Berkeley FSD, provided that adequate standards of film quality are maintained during the experimental run at the accelerator. (Joyce Crawford and Joan Pinchak)

The writing of a preliminary diagnostic program (434) to detect format deviations in the data transmitted by the FSD was completed, and the program partially debugged. This program is already being used as an aid in checking the consistency of FSD hardware performance.

Test patterns that can be positioned and measured automatically have been fabricated and operated on the FSD. The patterns are a preliminary to a more advanced diagnostic and calibration program to be written in the near future. (Bud Koger)

FOG

A new dictionary of error codes was formulated for HAZE and FOG processing

(see HAZE). This dictionary classifies particular errors into either view or track failures, and indicates by code where in the process from scanning through space reconstruction the error occurred. Using these new error codes, program 135B produces an error summary which gives the percentages of failure for each class of error, and for each class of error breaks down the analysis according to view. Quality control over large amounts of data is materially improved.

Program 135B now produces an event catalog, which identifies each event input to the program, and if events fail indicates the particular cause for the failure by using the new error codes.

Program 134 was modified to have the option of producing a library catalog listing events from subsets as well as from entire experiments.

A least-squares fit of  $n$  measurements ( $3 \leq n \leq 7$ ) was debugged, and this routine is now used on all FSD measured data.

The 80-inch hydrogen chamber's optical constants and magnetic field routine were checked out early in this period. The 100-cm CERN chamber's optical constants and magnetic field routine were coded and check-out was started. (Shirley Buckman)

Program 147, which generates a FOG library consisting of events selected from another library by a matching operation with a FAIR page tape, was debugged and put into routine production status. It is thereby possible to perform an associative retrieval of data at the FOG library level. (Loren Shalz)

An extension to the main geometry program (135) was developed which will perform a maximum-likelihood determination of the momentum and position vectors at the vertex, using data from all available views. In addition the program will provide a reliable detection and correction function for otherwise undetected measurement errors. This extension was developed, flow-charted, written, and partially debugged during this period. (Dennis Hall, Frank Windorski, Joan Franz)

CLOUDY

Debugging was completed of a disc-utilization feature in program 209 which eliminates the requirement of multiple passes and greatly improves the running time for compli-

cated event types.

A special-purpose beam-editing program for neutral beams was written and debugged. This feature computes the line of flight of the neutral particle together with its weight matrix from the measured position of the vertex and the known position and dimensions of the target.

Program 208 was modified to accept an intermediate change to the FOG library format. This feature will allow debugging and limited production of the new multiview mass-dependent fitting procedure in FOG.

Several new experiments were also set up for the CLOUDY programs. (Vivian Morgan and Frank Windorski)

#### FAIR

A limited number of special calculations were programmed. A special routine to generate Hold card images on a tape for certain level definitions was written and used extensively, allowing more flexible use of the event-selection procedure.

The FAIR merge program (411) was reassembled for operation under the TRIST multiprogramming monitor.

Flow charting in anticipation of a reassembly of program 304 continued. The following list enumerates some of the more important modifications.

Extension of the SAVE list area from 250 parameters to 500 parameters.

A more general logical compiler which uses a push-down stack principle.

Use of the 1301 disc module to keep separated the pages of the Hold card listing from the mass-permutation catalog.

Reuse of all memory space containing initialization routines by those routines required during execution time.  
(Loren Shalz)

#### DAPR

Prototype programs for track following, track linking, and vertex finding were run for the Berkeley 25-inch chamber, the Berkeley 72-inch chamber, and the Brookhaven 80-inch chamber. This was done as a final check of prototype program operations and to determine optimum settings for the various operating

thresholds.

Flow charts were completed for the prototype and diagnostic programs and program write-ups were made. A general description of the recent DAPR developments and results was written.

The DAPR production system was defined and work was begun on its implementation. (Joan Pinchak, David Budenears, Nan Jontulovic)

#### TRIST

A write-up of the TRIST executive program was completed and work continued on debugging of the B-level execution logic. Routine simultaneous running of A- and C-level programs continued during this period.

The time-accounting program (052) was completed and documented. This program reads time data produced by the TRIST executive and generates reports of the number of computer runs, the elapsed time, and the number of new chains processed by account number, run type (production, debug, etc.), program number, and experiment number. All data are merged for subsequent report-generating programs. (Carol Osborne and Joan Pinchak)

#### Event Accounting

Work was begun on an event-accounting program which will record all data pertinent to the status of each experiment. In particular, the processing history of each event from the time it is first scanned until it reaches a FAIR abstraction tape will be kept on an extremely compact event-accounting tape. Reports of the processing status of each experiment will be generated automatically. This feature will greatly facilitate the scheduling of computer time. Other reports will inform the experimenters of the status of their experiment, thus enabling them to assign their scanning and measuring staff more efficiently.

As a temporary measure, programs 430 and 433 were written. These read an edited scan-table tape and produce a catalog record for each event on an output tape. This tape is released to the individual experimenters for processing by their special-purpose FORTRAN programs. (Bill Wright, Carol Osborne, Shirley Buckman)

## DATA PROCESSING OPERATIONS

The following table summarizes the processing of both Franckenstein- and FSD-measured events. An event is the entire col-

lection of related vertices measured in a bubble chamber picture. New measurements are counted separately, but the effect of any reprocessing has been eliminated from the totals.

Event measurements analyzed			
Chamber	Beam	Group	Number of events
FRANCKENSTEIN			
30-Inch propane	Stopping $K^+$	Powell-Birge	152
20-Inch deuterium	3.7 BeV/c D	Powell-Birge	3 035
25-Inch hydrogen	0.850-1.150 BeV/c $K^-$	Powell-Birge	11 287
25-Inch deuterium	0.850-1.150 BeV/c $K^-$	Powell-Birge	17 723
			<u>32 197</u>
FSD			
25-Inch hydrogen	1.2-BeV/c $K^+$	Trilling-Goldhaber	2 288
25-Inch hydrogen	1.4-BeV/c $K^+$	Trilling-Goldhaber	6 493
25-Inch hydrogen	0.8-BeV/c $K^+$	Trilling-Goldhaber	23 080
80-Inch hydrogen	4-BeV/c $K^+$	Trilling-Goldhaber	15 037
25-Inch hydrogen	300 ± 120-MeV/c $K_2^0$	Trilling-Goldhaber	1 304
25-Inch hydrogen	0.8-1.4-BeV/c $K^-$	Powell-Birge	15 075
25-Inch deuterium	0.8-1.4-BeV/c $K^-$	Powell-Birge	515
72-Inch hydrogen	6-BeV/c P	Segrè-Chamberlain	8 541
			<u>72 333</u> ✓
		Total events analyzed	104 530

## REPORTS AND PAPERS ISSUED

1. Shirley Buckman, Joan Franz, John Gotthelfsman, Dennis Hall, Vivian Morgan, and Frank Windorski, The Multiview FOG Program and its Application to Quality Control of FSD Data: A paper presented at the Conference on Programming for Flying Spot Devices, Columbia University, October 1965 (UCID-2652, Oct. 1965).
2. Charles Dickens and Mary Downton, DAPR Revisited: Latest Results from the Berkeley Programs, UCID-2519, April 1965.
3. Charles Dickens, Mary Downton, Joan Pinchak, and Howard S. White, Results from Prototype DAPR Programs: A paper presented at the Conference on Programming for Flying Spot Devices, Columbia University, October

1965 (UCID-2653, Oct. 1965).

4. Dennis Hall, Joan Pinchak, and Howard S. White, The DAPR Production System: A paper presented at the Conference on Programming for Flying Spot Devices, Columbia University, October 1965 (UCID-2654, Oct. 1965).

5. Carol Osborne, Robert Larson, Thomas Oliver, Joan Stekler, and Howard S. White, TRIST, a Tri-level Multiprogramming Executive Involving Real-Time Calculations and an Asynchronous On-Line Data Search, UCRL-16481, Oct. 1965.

6. H. S. White, Status and Future Plans for LRL Flying Spot Digitizer: A paper presented at the High Energy Instrumentation Conference, Purdue University, May 1965 (UCID-2528, May 1965).

HEALTH PHYSICS

H. Wade Patterson in charge

## THRESHOLD DETECTORS

We have developed a method of using threshold detectors for measuring neutron spectra which depends on the activation of various elements by (n, p), (n,  $\alpha$ ), and (n, 2n) reactions and on the counting rate observed in moderated  $\text{BF}_3$  and Bi fission chambers. Knowledge of the various cross sections allows us to calculate the activities and counting rates that would be produced in an array of active and passive detectors by an assumed neutron spectrum. These calculated rates are compared with those actually observed, and the comparison is repeated with appropriate changes in the assumed neutron spectrum until it produces activities which match those actually observed. We use this technique to measure neutron spectra produced at an accelerator target, to evaluate shielding, and to estimate personnel exposures. The results

obtained agree well with data on neutron spectra taken with nuclear emulsion; we are now trying to extend its usefulness to higher neutron energies.

## NUCLEAR EMULSION

For some time we have used nuclear emulsion for neutron spectrometry by way of proton-recoil track-length analysis. Recently we have found that there is a measurable correspondence between the number of gray prongs per star and average neutron energy. Emulsions were exposed to neutrons of average energy from 20 to 300 MeV and the number of gray prongs per star was found to vary from  $10^{-2}$  to  $5 \times 10^{-1}$ . We are now examining this relation in emulsions that were exposed to neutrons outside accelerator shields rather than to the primary neutrons from accelerator targets.

ACCELERATOR OPERATION AND DEVELOPMENTACCELERATOR STUDY GROUP

Edward J. Lofgren in charge

The Accelerator Study Group has issued and distributed a report, 200 BeV Accelerator Design Study (UCRL-16000, Vol. I and II, June 1965), which describes the design of the accelerator, initial experimental facilities, and support facilities, and estimates the scale of operation of the laboratory several years after turn-on. Costs are estimated for both construction and operation. The scope and costs of the project are being reviewed by Daniel, Urbahn, Seelye, and Fuller (DUSAF), an Architect-Engineering firm, for the AEC.

Review and further improvement on

the design are in progress, and laboratory work is being undertaken to develop machine components. Development work is proceeding in the following areas:

- (a) Full-scale modeling of the main ring gradient-magnet system to investigate both magnetic and mechanical properties.
- (b) Radio-frequency accelerating system development for main ring, injector synchrotron, and linear accelerator.
- (c) Accelerator control system.
- (d) Shielding experiments.
- (e) Ring magnet power supply.

BEVATRON

Edward J. Lofgren in charge

Reports on Bevatron Operation and  
Development are issued on a quarterly basis.  
Reports are being prepared to cover the period

April through June 1965 (Report 46, UCRL-  
16553) and July through September 1965  
(Report 47, UCRL-16554).

## 184-INCH CYCLOTRON

David L. Judd in charge

Reported by James T. Vale

### OPERATION

The cyclotron was used for research experiments more than 95% of the time the crew was on duty.

Since innage was so high, very little was done to change the cyclotron, only routine maintenance was carried out.

Additional high-density shielding blocks for the external beam caves have been received and installed. These improved blocks have lowered the background radiation level, and offer a distinct advantage over the old concrete blocks.

The experimental magnets have been protected thermally by means of the fusible-link type of interlock. These interlocks have not been very satisfactory, especially for magnets that are imbedded within a shielding wall. If the interlock system opens, one cannot determine, without unpling the shielding blocks to get to the interlocks, whether the magnet has overheated or the interlock system has malfunctioned. It was decided some time ago to replace these fusible links with snap-action switches (Klixon brand), so that they would at least reset automatically when an overheated part cooled down. The changeover on these magnets to the Klixon devices is now fairly complete.

### MODEL STUDIES

A program was initiated some time ago to study beam conditions in synchrocyclotrons with the express purpose of applying findings to the 184-inch cyclotron. It is impractical to do this study on the 184-inch cyclotron because of the high radioactivity present and because of the large experimental demand, therefore a model is being used. For this work, pole tips of 28-in. diameter were installed in an experimental bending magnet. Thus far, ions have been accelerated only to about a 4-in. radius, but since this corresponds to roughly 100 turns, considerable information can be obtained.

The ion source used is a Calutron type. However, mere large output from the source is not the key to large final beams. In synchrocyclotrons the duty cycle is roughly 1%. Therefore, to get ion beams in synchrocyclotrons comparable to those in continuous accelerators,

peak ion currents 100 times as high are necessary. Ion densities thus are high enough to become the limiting factor for ion-beam outputs from this type of accelerator. Verification is obtained by comparing beam outputs of synchrocyclotrons all over the world. The number of protons per pulse for all these machines is roughly the same. This still holds true in spite of all the various types of ion sources that may be used. It is by space charge that ion beams are limited in all these accelerators.

The 28-inch model was constructed to study this space-charge limitation and to attempt to overcome it. Ion beam currents at a 4-in. radius are not linearly proportional to ion source output. Higher beam currents are obtained with a 4-mA source output than with 40 mA, because proportionately more ions are lost at the higher ion densities.

Focusing forces counter to space-charge forces can be used to help overcome the ion loss. Magnetic cones on the center regions of the pole pieces have been used in these accelerators for years for increased beam output. These cones provide magnetic focusing in the center region.

In the model, focusing grid wires were used in addition to the magnetic cones. Tungsten wires 0.003 in. in diameter were used. The grids were installed on the dee and on the dummy dee on alternate sides of the vertical center line so that the ions "saw" the grids when leaving the gap. This produced the well-known focusing electric field in the gap.

The beam current obtained with these grids is an order of magnitude higher than without them. However, the grids are not without fault; they intercept beam, and the larger the radius, the more beam is intercepted, because the ion orbits get closer together at increased radius. These wires were installed only to a 3-in. radius, and the last wire was a bright red temperature from the beam that hit it. The wires, therefore, cannot be applied much beyond this point, and magnetic focusing must be used.

The next step with the model is to try magnetic focusing. First, however, the magnetic field and frequency of the rf system is to be raised to bring them closer to that of the 184-inch cyclotron. This is now in progress.

88-INCH CYCLOTRON

H. E. Conzett in charge

## OPERATION

The distribution of cyclotron time during the period May through October 1965 was:

	<u>8-hr shifts</u>	<u>%</u>
Nuclear reactions and scattering research	292.5	54
Biomedical research	20.5	4
Isotope production	120.5	22.5
Cyclotron research	52.5	10
Scheduled shutdowns, preventive maintenance	43	8
Repairs (unscheduled)	8	1.5
Total	<u>537</u>	<u>100</u>

CYCLOTRON  
RESEARCH AND DEVELOPMENT

The regenerative deflection system was completed, and it was installed during a shutdown started in late October 1965.

The beam transport and monitoring equipment, just downstream from the cyclotron exit port, was redesigned and consolidated for installation during the shutdown. A small horizontal-steering magnet was included to provide more flexible beam coupling between the cyclotron and the external beam-transport system.

Developmental studies of axial injection of ions were continued. A full-scale pilot

model of the ion source and ion transport system was built, thus making it possible to study the ion beam under conditions that simulate axial injection into the cyclotron.

A control system has been designed to provide automatic setting of many of the cyclotron parameters,<sup>1</sup> and some of the hardware has been selected. The system is expected to reduce from about 30 to 5 minutes the time required for a change in beam particle or energy or both, and it will provide more reliable setting and monitoring than is possible through manual control.

Development of new beams of He<sup>3</sup> ions continued. He<sup>3</sup> beams from 20 to 140 MeV are now available. Computer studies were begun of beams in the center region of the cyclotron. Also, continued studies were made of the quality of the external beam under various conditions of cyclotron operation. With careful centering of the beam and selective setting of oscillator frequency and dee voltage, energy dispersions as low as 0.2% were achieved for 65-MeV He<sup>4</sup> beams.

## EXPERIMENTAL RESEARCH

Beams of protons, deuterons, He<sup>3</sup>, and He<sup>4</sup> have been provided for a large variety of experiments in nuclear reactions, scattering, and fission research. Detailed reports describing the results are contained in the current Chemistry Division Annual Report.

1. David R. Struthers, Automatic-Control-System Design for the Berkeley 88-Inch Cyclotron, UCRL-16210, June, 1965.

ELECTRON LINEAR ACCELERATOR

David L. Judd in charge

Reported by Douglas W. Pounds

## OPERATION

During the period May through October the group utilization of the machine was as follows:

<u>Group</u>	<u>Hours</u>
Biomedical Research	208
Livermore Chemistry	88
Princeton Research Group (via Alvarez)	80
Berkeley Nuclear Chemistry	56
Bio-Organic Chemistry	56
Health Physics	12
Health Chemistry	8
Soil Sciences	1.5
Total	509.5

Available Hours: (one man for one shift)

6 mo. $\times$ 4 $\frac{1}{3}$ weeks $\times$ 40 hours	1040 hours
Minus vacation	80 hrs
holidays	24 hrs
sick leave	32 hrs
	136

Net hours available 1004

Utilization of the available machine time (509.5/1004)  $\approx$  51%

The lower-than-normal utilization of the Linac during this period reflects an absence of the usual dozen or more "One-Shot" experimenters and two or three small-use experimenters that have been a part of the past linac programs.

## RESEARCH PROGRAMS

The dominant program during this period has been the study of radical spectra and 4.2°K. Equipment difficulties and space

limitations have hampered the development of this program, but these restrictions are being resolved. Other programs during this interval have been crystal expansion by radiation fields, radiation creep in plastics, nuclear magnetic resonance at liquid nitrogen temperatures, evolution of organic chemicals (origin of life), mechanism of radiation damage to living organisms, Cerenkov counter calibrations, dosimetry calibrations, and soil sterilization.

Machine development has been limited to minor modifications of the power supplies, pulse lines, and Klystron driver systems. The plans for increasing the linac energy to 25 MeV have been deferred.

Machine parameters for  $e^-$  are at this time:

Energy	3 to 10 MeV
Pulse repetition rate	1 to 120 pps
Pulse length	7 $\mu$ sec
Beam intensity	0 to 150 mA/pulse
Exposure rate	0 to $1.5 \times 10^8$ R/min

Linac facilities during this interval show an increase in total area allocated to the linac, with most of the gain going to experimenter work area. This additional space was needed by the expanding EPR (electron paramagnetic resonance) program, and has already been absorbed by the Biomedical group.

Outlook for the coming 6-month period is of an increase in the EPR activity with the addition of two Ph. D.'s to the research staff, commencement of a long-term materials-testing program headed by Jim Turner of Mechanical Engineering, a return of the NASA "chemical evolution" program from the Ames Research Center group, and probable continuation of existing projects. The general expectation is for an increase in experimenter activity at the linac during the next half year.

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