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PHYSICS DIVISION SEMI-ANNUAL REPORT

November 1965 through April 1966

Berkeley, California

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GENERAL PHYSICS RESEARCHPHYSICS RESEARCH

Luis W. Alvarez in charge

Research projects reported below have been carried out by the following (as indicated by the initials at the end of each report): Maris A. Abolins (MAA), Margaret H. Alston (MHA), Luis W. Alvarez (LWA), Jared A. Anderson (JAA), Roger O. Bangerter (ROB), Angela Barbaro-Galtieri (ABG), J. Peter Berge (JPB), Rudolf K. Bock (RKB), Suh Urk Chung (SUC), Frank S. Crawford, Jr. (FSC), Orin I. Dahl (OID), Jerome S. Danburg (JSD), Joseph C. Doyle (JCD), Billy C. Ellis (BCE), Philippe Eberhard (PE), Stanley M. Flatté (SMF), Jerome H. Friedman (JHF), Eugene Gellert (EG), Lawrence K. Gershwint (LKG), Robert L. Golden (RLG), Ronald A. Grossman (RAG), David Herndon (DH), Lyndon M. Hardy (LMH), Richard I. Hess (RIH), Paul L. Hoch (PLH), J. Richard Hubbard (JRH), William E. Humphrey (WEH), Laurance D. Jacobs (LDJ), Janos Kirz (JK), James Lindsey (JL), Lester J. Lloyd (LJL), Gerald R. Lynch (GRL), Jerry Manning (JM), Terry S. Mast (TSM), Gerald W. Meisner (GWM), Deane W. Merrill (DWM), Donald H. Miller (DHM), Joseph J. Murray (JJM), Monique L. Neveu (MLN), LeRoy R. Price (LRP), Morris Pripstein (MP), Alan Rittenberg (AR), Arthur H. Rosenfeld (AHR), Ronald R. Ross (RRR), Janice B. Shafer (JBS), Frank Shively (FS), Dennis B. Smith (DBS), Gerald A. Smith (GAS), Lawrence H. Smith (LHS), Robert G. Smits (RGS), Frank T. Solmitz (FTS), M. Lynn Stevenson (MLS), Alexander V. Stirling (AVS), Robert D. Tripp (RDT), Robert D. Watt (RDW), Bryan Webber (BW), A. Barry Wicklund (ABW), Charles G. Wohl (CGW), Stanley G. Wojcicki (SGW).

RESEARCH WITH BUBBLE CHAMBERS

Associated Production Experiment

Between mid-1960 and mid-1964, the 72-inch hydrogen bubble chamber was exposed to π^+ and π^- beams at six laboratory momenta from 1.030 and 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 π^- 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 π^- incident at 1.170 BeV/c has been continued, as has the investigation of the reaction $\pi^- p \rightarrow \Lambda K^0$ with the π^- incident at momenta less than 1.030 BeV/c (the threshold for Σ production).

Study of n-p scattering where the neutrons come from Σ^+ decay, together with the known Σ^+ polarization, yields an estimate of the parameters γ for Σ^+ and Σ^- decay. (JAA, FSC, JCD)

Production of η Mesons

The analysis of 41 $\pi^+ p \rightarrow \pi^+ p \eta$ events at 1.050 BeV/c and of 113 $\pi^- p \rightarrow \pi^- p \eta$ and 64 $\pi^- p \rightarrow \pi^0 p \eta$ 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 ηp enhancement near threshold. If the effects are assumed not due to an ηp 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 πp system. Recent experiments on η production in the reaction $\pi^- p \rightarrow \eta n$ indicate the possible existence of an ηN 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, LRP, FSC)

Decay Modes of the η 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 $\eta \rightarrow \pi^+ \pi^- \pi^0$. An asymmetry between the π^+ and π^- energy distribution would indicate nonpreservation of C invariance. Detailed subtractions of background and corrections for "ambiguous pions" have been made. The corrected data are, within the limits of statistics, consistent with preservation of C invariance. [Frank Crawford and twenty-nine others, Search for C Violation in $\eta \rightarrow \pi^+ \pi^- \pi^0$ (UCRL-16693, Feb. 1966), submitted to Phys. Rev.]. (FSC, LRP, RAG)

Study of the Decay $\eta^0 \rightarrow \pi^+ \pi^- \gamma$

The branching ratio $\eta \rightarrow \pi^+ \pi^- \gamma / \pi^+ \pi^- \pi^0$ has been found to be $R = 0.30 \pm 0.06$. The study of π^+ and π^- energy distribution shows they are consistent with no large nonconservation C invariance. ¹ (FSC, LRP)

Leptonic Decays of K^0 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 has suggested that CP nonviolation in leptonic decays might explain CP mixing in K_2 decays. The explanation requires that the decay amplitudes be related by a $(K^0 \rightarrow e^+ \pi^- \nu) \approx \pm i a (K^0 \rightarrow e^+ \pi^0 \nu)$. The observed time distributions are consistent

with this relation but do not demand it. Sachs has also suggested a test for CPT nonconservation. The observed time distributions are consistent with CPT invariance. (RAG, FSC)

The K_1, K_2 Mass Difference

The data reduction of interactions of K^0 mesons has been completed. There are 70 hyperon-production events, 11 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 $(0.65 \pm 0.30) \tau_1^{-1}$. ² The charge-exchange events are being analyzed to test the mixing parameters of the neutral K meson system. The elastic scattering are being analyzed to determine the sign of the K_1, K_2 mass difference. (GWM, FSC)

1. Frank S. Crawford and Leroy R. Price, Phys. Rev. Letters 16, 333 (1966).
2. Gerald W. Meisner, Bevalyn B. Crawford, and Frank S. Crawford, Phys. Rev. Letters 16, 278 (1966).

π 63 Experiment

This was an exposure totaling 30 000 events/mb of the 72 inch hydrogen bubble chamber to a π^- 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.

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

Approximately 250 events were observed in which the deuteron survived. The events are dominated by the ρ^0 production; in addition, the $\pi^- d$ effective-mass distribution peaks at 2170 MeV, where the π^- can interact strongly with either nucleon in the N_{355} 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 enhancements. (DHM)

Production of Φ 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 $\pi^- p \rightarrow n k^+ K^-$ 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 Φ meson. A preliminary study of the decay angular correlations indicates that the $\sin^2\theta$ dependence expected for production through ρ exchange is markedly distorted due to absorptive effects. This is similar to the situation observed in the reaction $\pi^-d \rightarrow \omega p$ (p). (RIH, SUC, OID, LMH, JK, DHM)

Analysis of the B Enhancement

In a continuing study of π^-p interactions at 3.2 and 4.2 GeV/c, 1,600 events of the reaction $\pi^-p \rightarrow \pi^-p$ have been identified. The effective mass distribution for the $\pi^- \omega$ system shows a strong enhancement³ at $M_{\pi^- \omega}$ 1200 MeV with $\Gamma \approx 130$ MeV, known as the B meson. It is shown that this enhancement can be explained in terms of the kinematic mechanism proposed by Deck⁴ and later elaborated upon by Maor and O'Halloran.⁵ (SUC, MLN, OID, JK, DHM)

Analysis of the $\pi\pi$ Phase Shifts

The analysis of the 13 000 events fitting $\pi^-p \rightarrow N\pi\pi$ in the $\pi 63$ two-prong experiment has continued. When combined with a further 10 000 events to improve statistics, the data were interpreted according to the one-pion exchange model and a value of $T=0$, S-wave $\pi\pi$ phase shift at 450 MeV of 45 ± 10 deg was obtained.⁶ Further work is in progress to give the value of this phase shift over the whole $\pi\pi$ mass range, together with a fit to the density matrix elements for the decay of the ρ meson, assuming a plausible form for the absorption modification to the one-pion exchange model. (LDJ)

3. Suh Urk Chung, Monique Neveu-René, Orin I. Dahl, Janos Kirz, Donald H. Miller, and Zaven Guiragossian, Phys. Rev. Letters 16, 481 (1966).

4. Lawrence D. Jacobs and Walter Selove, Phys. Rev. Letters 16, 669 (1966).

5. R. T. Deck, Phys. Rev. Letters 13, 169 (1964).

6. U. Maor and T. A. O'Halloran, Jr., Phys. Letters 15, 281 (1965).

$\pi 66$ Experiment

At the time of reporting, the 72-inch hydrogen bubble chamber is filled with deuterium, and is being exposed to π^+ mesons in the range 3.7 to 4.2 BeV/c. The analysis of the experiment is primarily directed toward the exploration of neutral mesons decaying into

$K\bar{K}$ pairs with or without additional π mesons, as well as other meson states. This experiment is performed in collaboration with groups from Purdue University and the University of Illinois. (MA, OID, JD, PLH, JK, DHM)

K 72 Experiment

This experiment was started in 1961. The 72-inch hydrogen bubble chamber has been exposed to a separated K^- beam for a total K^- path length corresponding to 14 000 events/mb. Beam momenta used were 1.05, 1.11, 1.22, 1.33, 1.42, 1.51, 1.60 and 1.7 BeV/c. Most of the results from this experiment have already been published.

The Reactions $K^-p \rightarrow \bar{K}^0n$ and $K^-p \rightarrow \Lambda\pi^0$ (K 72)

The completed analysis yielded 4 000 \bar{K}^0n events and 7 000 $\Lambda\pi^0$ events. Effects of peripheral production are evident in both channels down at least to 1.5 BeV/c. Analysis of production and (for the $\Lambda\pi^0$ events) polarization angular distributions reveals two Y^* resonances. Their properties are

(a) $(I, J^P) = (1, 7/2^+)$, $\omega_0 = 2030$ MeV, $\Gamma = 170$ MeV, $X_{\bar{K}N} = \Gamma_{\bar{K}N}/\Gamma = 0.20$, $X_{\Lambda\pi} = 0.20$;

(b) $(I, J^P) = (0, 7/2^-)$, $\omega'_0 = 2110$ MeV, $\Gamma' = 150$ MeV, $X'_{\bar{K}N} = 0.30$. (LG, FTS, MLS, CGW)

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

Of the two-body reactions, 5040 events fit $\Sigma^+\pi^-$ and 2322 events fit $\Sigma^-\pi^+$. Both charged states show evidence for the formation of $Y_1^*(2030)$ and $Y_0^*(2090)$. The analysis of production and polarization angular distributions is in agreement with the quantum numbers assignment ($JP = 7/2^+$ and $7/2^-$ respectively) found in the analysis of \bar{K}^0N and $\Lambda\pi$ channels. The $K^-p \rightarrow \Sigma^+\pi^-$ reaction shows presence of K^* -exchange amplitude in addition to the resonant amplitudes of the $Y_0^*(2030)$ and $Y_1^*(2090)$.

Of the three-body reactions, 5240 fit $\Sigma^+\pi^-\pi^0$ and 4400 fit $\Sigma^-\pi^+\pi^0$. The known hyperon resonances are produced and some $Kp \rightarrow \Sigma^\pm p \pi$ reactions are observed. (ABG, MHA, AHR)

The Reaction $K^-p \rightarrow \Lambda\omega$ at 1.2 to 1.8 BeV/c

Both total and differential cross sections, for the reaction $K^-p \rightarrow \Lambda\omega$ have been determined within the regions $(1.88 \text{ BeV})^2 < s < (2.09 \text{ BeV})^2$,

7. Philippe Eberhard and five others, The Reaction $K^-p \rightarrow \Lambda\omega$, 1.2 to 1.8 BeV, (UCRL-11982, Oct. 1965), Phys. Rev. (to be published).

where s is the total c. m. energy squared, and $-(1.28 \text{ BeV})^2 < t < -(0.29 \text{ BeV})^2$, where t is the four-momentum transfer squared. The decay angular correlations of the Λ decay products ($p\pi^-$) and the ω decay products ($\pi^+\pi^-\pi^0$) have been systematically determined. In three subregions of s and t , the six production amplitudes that describe the reaction have been determined. It is shown that no simple exchange models explain the data and that no striking resonance formation in the direct channel is taking place. (PE, SMF, DOH, JBS, FTS, MLS)

Properties of Ξ Production and Decay

The analysis of the 1004 Ξ^- and 206 Ξ^0 events produced in this experiment has been completed. Final results have been accepted for publication.⁸ A thesis on the Ξ^0 analysis has been completed (J. Richard Hubbard, Properties of the Neutral Cascade Hyperon, UCRL-11510, April 1966). (JPB, JRH, DWM, JBS, FTS, MLS)

Decay Properties of the ω Meson

The reaction $K^-p \rightarrow \Lambda\omega$, as observed in the Lawrence Radiation Laboratory's 72-inch hydrogen bubble chamber, has provided more than 4600 examples of ω decay. The distribution of pion momenta in the decay $\omega \rightarrow \pi^+\pi^-\pi^0$, of which 4200 examples have been seen, is found to be consistent with C conservation. With the assumption that the ω spin is 1^- , the pion-momentum distributions predicted by two different decay matrix elements are compared with the experimental distributions, as a test for final-state interactions. It is also shown that a spin of 3^- for the ω is unlikely. Branching fractions of other decay modes with respect to the $\pi^+\pi^-\pi^0$ decay mode are: neutrals, 0.097 ± 0.016 ; $\eta\gamma$, < 0.017 ; $\eta\pi^0$, < 0.017 ; $\pi^+\pi^-\gamma$, < 0.05 ; e^+e^- , < 0.0003 ; and $\mu^+\mu^-$, < 0.0017 . The $\omega \rightarrow \pi^+\pi^-$ branching fraction lies between $(0.17 \pm 0.03)^2 = 0.029$ (coherence between the ρ and the ω production amplitudes assumed) and 0.082 ± 0.020 (incoherence assumed). (SMF, DOH, JJM, JBS, FTS, MLS, CGW)

8. J. Peter Berge and six others, Some Properties of the Ξ^- and Ξ^0 Hyperons Produced in K^-p Interactions (UCRL-11529, Sept. 1965), submitted to Phys. Rev.

9. Stanley M. Flatté and six others, Decay Properties of the ω Meson (UCRL-16443, Oct. 1965), Phys. Rev. (to be published).

The Reaction $K^-p \rightarrow \Lambda\omega$ Between 1.2 and 2.7 BeV/c

More than 9000 $K^-p \rightarrow \Lambda\omega \rightarrow (p\pi^-)(\pi^+\pi^-\pi^0)$ events in four momentum regions from 1.2 to 2.7 BeV/c have been analyzed. The differential cross section and the eleven independent decay-correlation parameters as a function of production angle have been systematically determined for each of the four momentum regions. The total cross section for $K^-p \rightarrow \Lambda\omega \rightarrow \Lambda(\pi^+\pi^-\pi^0)$ at 2.1 BeV/c is 0.46 ± 0.05 mb and at 2.6 BeV/c it is 0.28 ± 0.03 mb. A striking forward peak in the differential cross section at 2.6 BeV/c suggests the appearance of strange-meson exchange. A new formalism for the absorption model has been used to show that the behavior of the differential cross section and the decay-correlation parameters as a function of production angle is qualitatively explained by the absorption model with K and K^* exchange. The absorption model has been applied to recently available data on $K^-p \rightarrow \Lambda\phi$; a successful qualitative fit has been obtained and the comparison between the couplings of $K^-p \rightarrow \Lambda\phi$ is in reasonable agreement with SU(3) predictions. [Stanley M. Flatté, The Reaction $K^-p \rightarrow \Lambda\omega$ from 1.2 to 2.7 BeV/c: The Absorption Model with Strange-Meson Exchange (Ph. D. Thesis), UCRL-16648, March 1966.] (SMF)

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

See first abstract of section on K 63 Experiment.

K 63 Experiment

This was an exposure, totaling 30 000 events/mb, of the 72-inch hydrogen bubble chamber to a K^- beam having laboratory-system 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 γ rays and thus detect neutrals. The film was taken between mid-1963 and early 1965.

[Referred to in the last abstract of the previous section, K 72 Experiment].

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

Measurements of about 150 000 two-prong K^-p interactions in the 72-inch chamber

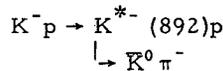
have been made with the Spiral Reader. The final state K^-p , $K^-p\pi^0$, and $K^-n\pi^+$ are being studied at momenta from 1.2 BeV/c to 2.7 BeV/c. Preliminary results on the differential elastic cross section have been reported. These data provide supporting evidence for the existence of two spin-7/2 resonances with masses near 2060 MeV. (GL)

The Reactions $K^-p \rightarrow \bar{K}^0 n$ and $K^-p \rightarrow \Lambda \pi^0$ (K 63)

We are presently cleaning up the events by comparing and resolving discrepancies between two scans of the film and remeasuring previously failing events. Preliminary analysis shows that peripheral mechanisms dominate the reactions. We will attempt to fit the angular distributions with a Regge-exchange model. (ABG, FS, RDT, CGW)

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

We have measured¹⁰ the total cross section, differential cross section, and $K^*(892)$ decay correlations for the reaction



at the K^- incident beam momenta 2.1, 2.45, and 2.64 BeV/c. Experimental decay distributions are consistent with the production and decay of a K^* relatively free from interference with other processes. The 4300 K^* events in the sample allowed us to determine the decay correlations as a function of production angle. Comparison of these correlations with simple meson-exchange models implies that pseudo-scalar-meson exchange dominates the extreme forward direction, while vector-meson exchange seems to be responsible for the decay correlations at larger angles. (JHF, RRR)

10. J. H. Friedman and R. R. Ross, Phys. Rev. Letters 16, 485 (1966).

Studied of $\Sigma^\pm \pi^\mp$ and $\Sigma^\pm \pi^\mp \pi^0$

Measurements and analysis of this topology have continued. In the three-body final state tentative results on the cross sections of $Y^* \pi$ and Σ at the various energies have been found, and studies on the production and decay characteristics of $Y^*(1385, 1405, 1520$ and $1660)$ and ρ are in progress. Cross sections and angular distributions of the two-body final states are being compiled. A general study on the scanning and analysis biases for charged sigmas has been started. (RBK, ABG, PE, FS)

$K^-p \rightarrow \Sigma^\pm \pi^\mp \pi^\pm \pi^\mp$

The analysis of this final state is continuing. Progress has been made in the analysis of the 1660 and 2060 resonances as they decay

in such modes. Final results are dependent on the study of different sorts of biases now in progress. (PE, RKB, MP, FS, AVS)

The Reactions $K^- + p \rightarrow \Xi + K$, $\Xi + K + \pi$ and $\Xi + K + \pi + \pi$

A sample of 2500 Ξ^- and 500 Ξ^0 hyperons in ΞK , $\Xi K \pi$, and $\Xi K \pi \pi$ final states at incident K^- momenta of 1.7 to 2.7 BeV/c has been analyzed. We observe $\Xi^*(1530)$, $\Xi^*(1817)$, and less clearly) Ξ^* resonances near 1700 and 1900 MeV. We have investigated the spin and parity of $\Xi^*(1530)$ and $\Xi^*(1817)$, and we have measured the $\Xi^*(1530)$ electromagnetic mass difference $\Delta M = M(\Xi^{*-}) - M(\Xi^{*0})$. For the Ξ , we have determined the spin and decay parameters α_{Ξ^-} and Φ_{Ξ^-} from a combined sample including 900 Ξ^- and 150 Ξ^0 events from the K 72 experiment. The following results were obtained:

Ξ^- and Ξ^0 : $J=1/2$ favored by 2.5 standard deviations;

$$\alpha_{\Xi^-} = -0.41 \pm 0.04, \quad \Phi_{\Xi^-} = 0.22 \pm 0.16 \text{ radians};$$

$$\alpha_{\Xi^0} = -0.45 \pm 0.11, \quad \Phi_{\Xi^0} = 2.3_{-1.7}^{+0.8} \text{ radians.}$$

$\Xi^*(1530)$: $\Delta M = 1.9 \pm 3.0$ MeV;

$J \geq 3/2$ favored by ≈ 1.8 standard deviations;

$J^P = 3/2^+$ favored over $3/2^-$ by ≈ 2.8 s.d.;

$\Xi^*(1817)$: $J^P = 1/2^{+-}$ or $3/2^-$, $5/2^+$, $7/2^-$ etc., indicated, but not firm due to sizable background in sample.

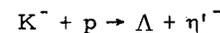
Analysis of the decay mode $\Xi^*(1817) \rightarrow \Lambda + \bar{K}$ yields results consistent with the above conclusions. [Deane W. Merrill, Decay Properties of the Ξ -Hyperon and Ξ^* Resonances, UCRL-16455 (in preparation).] (JBS, JPB, JRH)

An analysis of the $\Xi^*(1530)$ in $\Xi K \pi \pi$ final states was published;¹¹ this report favored Ξ^* spin $\geq 3/2$ and $\Xi^* - \Xi$ parity even (odd parity having a confidence level ≤ 0.03). (JBS, JSL, JJM)

11. Janice B. Shafer, James S. Lindsay, and Joseph J. Murray, Phys. Rev. 142, 883(1966).

η' (958) Results

Study of the η' meson is continuing. Currently, we are processing deuterium events, in a search for the reaction



The absence of this reaction would confirm the assignment of I spin = 0 to the η' . The other supposed quantum numbers, $J^{PC} = 0^{-+}$, are being borne out by more careful study of the decay modes and production process of the η' in our hydrogen film. (AR)

K⁻ Interactions in Deuterium

The deuterium exposure of path length ≈ 5 events/ μ b equally divided between 2.1 and 2.64 BeV/c has been 90% scanned. Measurements have been made on 16 000 events of the following topologies: Three or four prongs with or without a secondary decay, and one to four prongs with a V. During this period special emphasis has been placed on measuring the three- and four-prong with V events, of which three-fourths are now measured. From these events, those fitting the reaction $K^- n \rightarrow \Lambda + X^-$, $X^- \rightarrow \pi^+ \pi^- \pi^+ \pi^-$ + neutrals are being studied to determine the isospin of η' (958). Tentative results confirm our earlier assignment $I = 0$. (AB-G, AR, FS, RDT)

Other Studies

During the report period analysis continued on the final states involving the ϕ meson and resulted in two publications: one concerning the branching ratios,¹² and one concerning production properties¹³ of this meson. A continuing study of the η (958) and η (549) gave limits on the amount of C nonconservation in these decays.¹⁴

12. James S. Lindsey and Gerald A. Smith, Phys. Rev. Letters 20, 93 (1966).
13. James S. Lindsey, Production Properties and Decay Modes of the ϕ Meson (Ph. D. Thesis), UCRL-16526, Dec. 1965.
14. Alan Rittenberg and George Kalbfleisch, Phys. Rev. Letters 15, 556 (1965).

p 65 Experiment

On approximately November 1, 1965, we completed an exposure of the 72-inch hydrogen bubble chamber to 5.5- and 6.6-BeV/c protons from the Bevatron. The protons were extracted in Channel II of the EPB, requiring about 10^{10} protons per pulse. During April 1966 additional pictures at 6.6 BeV/c in deuterium were taken in the same beam facility. The total exposure amounted to 600 000 pictures (500 000 in H₂, 100 000 in D₂).

The hydrogen experiment was done in collaboration with the UCLA group. Collectively, we have completely scanned and partially rescanned all pictures for the production

of strange particles. The total sample amounts to about 20 000 events. Measurements of these events are essentially complete, and only events from the rescan plus events that failed in the first measurement are yet to be measured. This experiment is pioneering a new set of Alvarez programs (TVGP, SQUAW, ARROW), and presently we believe that data are ready for a detailed analysis in search for new resonances, etc.

We feel that a complete scan of the deuterium film would be most profitable only after we have completely analyzed the hydrogen film. This should commence in a month or two. (GS, SW, WW, AW, GG, RM)

K 65 Experiment

Since August 1965 the 25-inch hydrogen bubble chamber is being exposed to a K⁻ beam momentum of 400 MeV/c. So far 850 000 pictures have been taken, with an average of 6 K⁻ per picture. About 60% of the film has been scanned. At present 26 000 of the events have been measured in the topologies with a Σ , a Λ , or a K⁰.

Of the Σ^\pm events, 17 000 have been processed on the 7044 computer with the new programs TVGP, SQUAW, ARROW. Angular distributions and polarization (for $\Sigma^+ \rightarrow p\pi^0$ events) agree with the previously reported results in this momentum region. A study of these events to improve the knowledge about the Σ decay parameters is in progress.

In the K⁰ events a systematic study of the leptonic decays is under way; 2000 K⁰ events have been measured and processed.

Final-state interactions of 2000 events of the type $K^- p \rightarrow \Lambda 2\pi$ are being investigated. (MAA, ROB, ABG, FSC, DJH, GRL, TM, JJM, FTS, MLS, RDT, ABW)

D-D Experiment

The feasibility of an experiment to study deuteron-deuteron interactions at 4.5 GeV/c has been investigated. This experiment will use the external proton beam and the 72-inch bubble chamber. The preliminary tests turned out to be quite promising, and the experiment is scheduled for June 1966. (PE, RKB, MP, AVS)

OTHER RESEARCH PROJECTS

Radio-Frequency Detector for High-Energy Particles

In preparation for a 10- to 15-GeV/c K^- beam being planned for 1968 at SLAC, a special photomultiplier tube, the dynamic crossed-field electron multiplier (DCFEM), is being developed to detect high-energy particles which are bunched at radio frequency. The DCFEM consists of two parallel plates, about 2.5 cm long and 0.5 cm wide, one of which is treated with a photosensitive Cs_3Sb surface. An rf electric field is perpendicular to the plates and a constant magnetic field is parallel to the short sides of the plates. At one end of the sensitized plate photoelectrons are created by outside means, and at the other end is a hole with a collecting electrode behind. Photoelectrons which originate during the appropriate phase interval of the rf field are first accelerated away from the emitting surface and then returned with sufficient energy to multiply. A series of multiplying steps carries the output pulse to the collector. Thus the DCFEM is a phase-sensitive detector of light. Cerenkov radiation from fast-moving particles will be used to activate the DCFEM. (SMF, JJM, SW)

Determination of Mixing Parameters of the $K^0 - \bar{K}^0$ System by Means of Strong Interactions

The application of strong interactions of K^0 or \bar{K}^0 in hydrogen to test CPT, CP,

T invariance is investigated.¹⁵ (FSC)

15. Frank S. Crawford, Phys. Rev. Letters 16, 278 (1966).

Study of $K^0 - \bar{K}^0$ System

About the $K_0 - \bar{K}_0$ system,¹⁶ a limitation to the possible range of its basic parameters has been set in absence of any conservation law but unitarity. (PE)

Data on Elementary Particles and Resonant States

This project consists of a periodical compilation of the world's experimental data on elementary particles and resonant states. A new edition of tables and data-card listings has been published.¹⁷ Wallet cards of European and American sizes have been printed. (AHR, ABG, JK)

16. Philippe Eberhard, Phys. Rev. Letters 16, 150 (1966).

17. Art H. Rosenfeld, Angela Barbaro-Galtieri, Walter H. Barkas, Pierre Bastien, J. Kirz, and Matts Roos, Rev. Mod. Phys. 37, 633 (1965).

HIGH ALTITUDE RESEARCH

(Supported by NASA)

A pilot balloon flight is scheduled for June. This flight will serve to check (a) the operation of a Cerenkov threshold detector having a 40-BeV threshold, (b) cosmic-ray background and accidental rates, and (c) telemetry techniques. Other components in the package will include two spark chambers, scintillators, nuclear emulsions, and pulse-height analysis equipment. An investigation of heavy cosmic-ray components is planned as a portion of the background study.

Later this year we expect to fly an engineering flight which will be a full-scale prototype for our first physics flight. The Vacuum Dewar and gondola structure have been designed and put out for bid. The specifications of the balloon system required to

carry our gondola are also out for bid. We have been carrying out studies aimed at minimizing costs resulting from damage to our experimental package on landing. We have also been investigating possible economies during the launch phase of the ballooning operation.

The design of the superconducting magnet required for the physics flight has been completed (by Clyde Taylor of LRL Livermore), and magnet construction is now in the testing phase. Other equipment required for the physics flight--such as analysis equipment, large spark chambers, and temperature controls--is presently in design or development stages. (LWA, JAA, BCE, RIG, WEH, JBS, DBS, LHS, RGS, RRR)

BUBBLE CHAMBER OPERATION AND DEVELOPMENT

Robert D. Watt in charge

25-Inch Hydrogen Bubble Chamber

The chamber continued operation in the Murray 400-MeV/c K^- beam. All together 330 rolls ($\approx 5.6 \times 10^5$ pictures) have been taken.

72-Inch Hydrogen Bubble Chamber

The chamber continued operation for the following groups: Alvarez, Segrè-Chamberlain, Powell-Birge, UCLA, SLAC, and Purdue-Illinois.

A total of 1400 rolls of film ($\approx 9.8 \times 10^5$ pictures) was taken during the report period. Of these, 933 were taken with hydrogen and 467 with deuterium in the chamber.

Components for the conversion of the 72-inch chamber to a bellows-expanded 82-inch chamber are proceeding to completion. The main body of the chamber is scheduled to be cast in May. The bellows bid has been awarded and the bellows will be delivered in the fall. The new chamber window will arrive during the summer. The expansion system is presently undergoing tests.

DATA REDUCTION OPERATIONS

Personnel (Alvarez Scanning and Measuring Group)

The group averaged 74.7 full-time equivalents over the period November 1, 1965, through April 30, 1966. The maximum level reached was 77.96 full-time equivalents in December. Approximately 11.5% of these figures represents time taken as sick leave, vacation, holidays, etc., leaving an average of 66.1 full-time equivalents devoted to the

overall group effort.

The average effort during this period showed a decrease of 5.6% from the previous period because (a) many holidays fell during this period, and (b) the previous report period covered the summer months during which most of our student help works full time, and also during which we had the extra effort of the Youth Opportunity Campaign workers.

Scanning

Film from the 72-inch and 25-inch bubble chambers¹⁸ was scanned according to the breakdown shown in the table.

<u>Experiment</u>	<u>Scan and event type</u>	<u>Number of rolls</u>
APE	Second scan, Spiral Reader, Two-prongs	97
π 63	Ambiguities, twice failing events, conflicting, and cross-section scanning	>500
K 63	1. 2.7 BeV/c, second scan, all event types	203
	2. 2.63 BeV/c, second scan, all event types	335
	3. 2.45 BeV/c, second scan, all event types	113
	4. 2.58 BeV/c, second scan, all event types	245
	5. 2.1 BeV/c, second scan, all event types	230
	6. 2.1-BeV/c and 2.63-BeV/c deuterium, first scan strange-particle events	223
P 65	7. 2.1-BeV/c lead plate, first scan, vee'd events with γ -ray conversions in lead plates.	421
	1. 5.45 BeV/c, first scan, strange-particle events	176
	2. 6.6 BeV/c, first scan, strange-particle events	237

18. The only Alvarez Group experiment currently using 25-inch film is K 65.

π 66	First scan, 3.8 to 4.2 BeV/c, π^+ in deuterium, all vee'd events	86
K 65	First scan, 400 MeV/c, strange-particle events	193

Measuring

The following gives the production by machine:

<u>Franckenstein measuring projector</u>	<u>Number of events measured</u>	<u>Number of hours of measuring</u>
MP II A	19 026 ^a	2 031
MP II B	16 282	2 270
MP II C	24 203	2 520
MP II D	25 158	2 717

Total from Franckensteins	84 669	9 538

a. MP II A measured primarily 25-inch film during this report period.

<u>SMP measuring projector</u>	<u>Number of events measured</u>	<u>Number of hours of measuring</u>
SMP 1	6 887	676
SMP 2	1 342	114
SMP 3	3 610	340
SMP 4	5 616	468
SMP 5	5 198	557

Total from SMP's	22 653	2 155 ^b

Spiral Reader	173 084	2 355 ^c

b. The SMP's were undergoing a phase-out plan during this period, allowing for subsequent use of the on-line 7040. Complete phase-out was achieved just before the end of this report period.

c. The Spiral Reader was undergoing significant hardware changes during this period, accounting for most of the lost time.

Grand Total	280 406	14 048
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DATA REDUCTION DEVELOPMENT

SMP System

Richard W. Casey, Alice J. Lee, and Ron R. Ross

Efforts during this period have been expended primarily in:

- (a) routine maintenance and modification of the SMP programs,
- (b) checking the vertex intersection routine,

(c) conducting tests of the SMP Σ measurements.

This group has decided to discontinue SMP operation. The AEC will handle distribution of the SMP's.

SPIRAL READER DEVELOPMENT AND OPERATION

Lester J. Lloyd, Norman R. Anderson, Glenn T. Armstrong
James N. Baldrige, James H. Burkhard, Roy Carlson,
Alice T. Lee, John Stedman, and Neven Travis

During these 6 months 173 000 events have been measured by the Spiral Reader. This is an increase of 90 000 events over the preceding 6-month period. Development of faster and more reliable electronics has been completed, and improvements have been made in the operation control programs. Measuring rates are typically 80 to 100 events per hour.

Work has been under way for 3 months on the fabrication of the second Spiral Reader. This device will be of essentially the same design as the first Spiral Reader with certain improvement in the film-handling system and in illumination and optics. Design specifications include increase in scanning radius to permit measurement of longer bubble chamber tracks. Operation is expected about the middle of fiscal 1967.

Also development has been under way on film handling systems to permit simultaneous measurement of three-spool 35-mm and 50-mm film formats.

Spiral Reader (Programming)

The multivertex version of the Spiral Reader filter program POOH was developed and debugged on the IBM 7094. This program was converted to the CDC 6600, and successfully processes single-vertex and multivertex events. POOH is being recoded to obtain greater efficiency. The Spiral Reader optical calibration program has been converted to the CDC 6600. A preliminary version of a DDP-24 light-pen filter program for salvaging rejected Spiral Reader events was successful, and will be revised and converted to the CDC 6600.

PROGRAMMING REPORT

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

Personnel

The computer programs described in this report were written by

Benjamin F. Abington II	Barbara J. Cottrell
Margaret H. Alston	Orin I. Dahl
Glenn T. Armstrong	Cecil T. Draper
James N. Baldrige	Nancy L. Gould
J. Peter Berge	Marjorie S. Hutchinson
James H. Burkhard	A. David Johnson
Roy E. Carlson	Nancy K. Joseph
Richard W. Casey	Werner Koellner
Lynn J. Champomier	Max Leavitt

Alice J. Lee	Tomas R. Tonisson
Thomas H. Oliver	Neven D. Travis
E. A. Romascan	J. J. Wilson
Jon D. Stedman	

Introduction

The Alvarez Programming Group spent most of its effort in preparation for the CDC 6600 computer. New programs were written for this machine and some old programs were transcribed to run under the CDC operating system. Maintenance of existing IBM 7094

and 7044 programs was given high priority because of their support to the physics group.

General Information

The bubble chamber analysis programs which 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 which reconstructs a track in the space of the bubble chamber from measurements in two or three views of that track.¹⁹ SQUAW is a program which does multivertex kinematics fitting.²⁰ ARROW is a program to process SQUAW output through various physical calculations.²¹ 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.

19. F. T. Solmitz, A. D. Johnson, and T. B. Day, LRL Alvarez Programming Group Memo P-117, June 8, 1965.

20. O. I. Dahl, F. T. Solmitz, and T. B. Day, LRL-Alvarez Programming Group Memo P-126.

21. O. I. Dahl, LRL Alvarez Programming Group Memo P-124, August 3, 1965.

Scanning and Measuring Projector (SMP) Programs

(See Alvarez Data Reduction Development.)

Spiral Reader Programs

(See Alvarez Data Reduction Development.)

Geometric Track Reconstruction Programs

A revised version of TVGP²² is operative on the IBM 7044 and 7094. Several tests have been added, error calculations have been modified in order to obtain greater accuracy, and parts of the program have been condensed considerably. The handling of two-point tracks and tracks with large curvature errors was greatly improved. Routines using the optical parameters found by WEASEL were added as well as routines for the handling of the new packed binary output format. TVGP was converted to IBSYS version 13 on the 7094.²³

The revisions to TVGP described above have been incorporated into SIOUX for the CDC 6600. The input/output of SIOUX is being revised in order fully to exploit the advantage of the combined program in terms of running time and core storage.

22. N. L. Gould and F. T. Solmitz, LRL Alvarez Programming Group Memo TVGP-CHG-003, March 29, 1966.

23. E. A. Romascan, LRL Alvarez Programming Group Memo P-133, March 24, 1966.

SQUAW

The kinematic fitting program SQUAW was partially rewritten in order to make the program easier to modify and to remove some errors that existed in the first version.

Library Programs

Programs LYRIC II²⁴ is now operative on the 7044 as well as the 7094. Revisions were made which increased the efficiency of the library program, and an operation was added to enable the user to determine scanner efficiency.

All assembly language subroutines have been converted to Fortran IV for the CDC 6600, and most LYRIC operations have been debugged on the new computer.

24. M. S. Hutchinson, N. Joseph, and M. Leavitt, LRL Alvarez Programming Group Memo P-123, May 12, 1965.

SUMX

A version of SUMX developed and employed at CERN has been converted for use on the CDC 6600 at Berkeley.²⁵⁻²⁷ The program produced histograms and various plots, and is expected to be in production soon.

25. M. Leavitt, LRL Alvarez Programming Group Memo P-135, April 14, 1966.

26. M. Leavitt, LRL Alvarez Programming Group Memo P-136 Rev., April 27, 1966.

27. M. Leavitt, LRL Alvarez Programming Group Memo P-137, April 29, 1966.

Miscellaneous Support Programs

The following production programs have been converted to the CDC 6600: DICAPP, a differential cross section and polarization plot program; MINFUN²⁸ (a program which will find the minimum of a general function), and DSTEMAM²⁹ (data summary tape examine).

28. W. E. Humphrey and B. J. Cottrell, LRL Alvarez Programming Group Memo P-6 Revised March 10, 1966.

29. O. I. Dahl, G. Kalbfleisch and A. Rittenberg, LRL Alvarez Programming Group Memo P-54, January 26, 1965.

PHYSICS RESEARCH

Kenneth M. Crowe in charge

$\pi\pi$ INTERACTIONS IN $\pi^- + p \rightarrow 2\pi^0 + n$

Tin Maung and Ned Dairiki

The analysis of this 184-inch Cyclotron run has been completed. The results indicate that the effect of a low-energy π - π scattering length can be separated from the "0" enhancement by restricting the range of the π - π relative energy with adequate resolution. The analysis depends on the choice of the Bose symmetrization parameter in a manner similar to that found by Booth et al. in the analysis of π - π effects in the pd reactions. A choice of this radius of 1 pion Compton wavelength yields the s-wave π - π scattering length larger than 0.65 pion Compton wavelength with a 90% confidence. A better fit is obtained for larger scattering lengths and smaller Bose radii. These results are published in Phys. Rev. Letters 16[9], 374 (1966).

MESIC x RAYS--QUARTZ CRYSTAL
SPECTROMETER STUDY

Robert Shafer and D. Jenkins

The preliminary results published on the pion mass determination have been expanded for publication. Robert E. Shafer completed his thesis (Pion-Mass Measurement by Crystal Diffraction of x Rays, UCRL-16365, Dec. 1965), and papers on the work have been submitted to the journals. The uncertainty due to the π -nucleus interaction has been shown from the results of the following work to be unimportant.

PIONIC x RAYS--SEMICONDUCTOR STUDY

David A. Jenkins, Curtis Nunnally,
Toshi Yamazaki, Melvin K. Simmons,
Don Girvin, and Ray Kunselman

Two major runs were in progress during 1965. The results of the survey of pionic x-ray energy levels and yields are to be published in Phys. Rev. Letters (David A. Jenkins and Kenneth M. Crowe, Pi-Mesic Atoms). To summarize briefly, the nuclear shifts of pionic x-ray transitions were observed in s states in NaI studies at several laboratories. The p-state shifts were first observed by Astbury et al. with the curved quartz x-ray spectrometer (1964). The size and sign can be understood in terms of the strong p-state resonance in the pion nucleon $I = 3/2$ $J = 3/2$ state. Recently Erickson at CERN has studied the problem theoretically in greater detail, and has obtained a phenomenological model for the

shifts for the various levels 1s, 2p, 3d, 4f, etc., as well as predictions for the empirical constants based on the known pion-nucleon interactions. The results obtained so far are in agreement with, for example, the 3d \rightarrow 2p transition for various elements. The 4f \rightarrow 3d transition also agrees, with the preliminary accuracy of ± 1 keV. The 5g \rightarrow 4f transition in the heaviest elements is probably uncertain because of the strong dependence on nuclear radius parameters.

μ DECAY IN COPPER

Philip Beilin

The analysis of the effects of binding on the muon beta-decay spectrum is being submitted in thesis form by Mr. Philip Beilin. The results are compared with theory. The distortion of the top of the momentum spectrum is pronounced. The thesis includes a discussion of the possible sources for the small remaining discrepancy between experiment and theory; for example, the electrodynamic corrections have not been calculated for the system.

BRANCHING RATIO OF $K_{\pi 2}/K_{\mu 2}$

Robert Beck

The analysis of the counter data taken in a run (1961) preliminary to that cited above has yielded another result on the disputed $K_{\pi 2}/K_{\mu 2}$ ratio. The analysis is being submitted by Mr. Robert Beck as his Ph. D. thesis. The analysis of the results has been delayed because of a poor fit to the shape of the peaks, which has been traced to a small fraction of particles which strike the focusing quadrupole in front of the spectrometer and are degraded off the low side of the two-body peaks. Fortunately, the correction applies to both particle groups so that the result appears to be insensitive to the effect.

The result $K_{\mu 2}/K_{\pi 2} = 2.31 \pm 0.24$ seems to differ by two standard deviations from the currently accepted value, obtained, for example, by Trilling in a recent survey of all experiments. The thesis includes a detailed discussion of possible systematic errors which do not appear to be sufficient to resolve the discrepancy. Because of lack of agreement in the earlier data taken by entirely different techniques, one is forced to conclude that this situation is still confused.

PIONIC x RAYS

Kenneth M. Crowe, David A. Jenkins
and others

The study of the pionic x rays will continue in 1967. The present runs will be analyzed with particular attention to the following problems:

a. Remeasurement of the $2p \rightarrow 1s$ transition to obtain a check on the s-state shifts. The published data can be increased and improved. The isotopic effects, which are expected to be very large, will be measured to check with predictions.

b. The widths of the s-state levels can be observed and checked. At present only one level broadening in beryllium has been published, and we observe several others currently which are large and can be easily measured. The isotopic effect on the widths is also predicted to be large.

c. Similar information will be obtained on the p-state shifts and widths as well as on higher levels. Better resolution and backgrounds as well as improved stability will allow an important improvement in accuracy. Double-gain-stabilization, 4000-channel pulse detail analysis used with the PDP-5 computer will be applied.

d. Intensities of various lines will be studied systematically. Present results appear to show interesting atomic effects. A collaborative effort with members of the Segrè Group on such topics as the chemical effects in compounds and alloys is being pursued.

e. The absolute accuracy in the muonic x rays is presently relatively poor. If the accuracy of the Columbia, Chicago, and CERN efforts on this problem can be improved, work will be initiated on the apparatus described.

f. The work on the curved-crystal spectrometer has been interrupted until both its absolute accuracy and basic slow rates can best be matched to the problems. Improvements in backgrounds and rates are expected, and should proceed in 1967 and 1968.

✓ K^+ DECAY-- K_{e3}

Michael E. Zeller

A study of the decay mode $K^+ \rightarrow e^+ + \pi^0 + \nu$ was undertaken as one of the objectives of the K^+ experiment done in the Bevatron in 1964-65. Since the run ended we have been engaged mainly in constructing the computer programs necessary to process and analyze the data for the experiment. These programs have the following functions:

a. To recognize by use of Vidicon data tracks from four spark chambers.

b. To establish the momentum and initial coordinates of the orbit of the charged particle through the spectrometer.

c. To compare the above momentum with the range of the charged particle, thus determining its identity.

d. To correlate the tracks in the "gamma chamber" from electrons from the γ -ray conversion due to the π^0 decay to determine the trajectory and energy of the π^0 .

e. To remove all the above information from tape and present it in the form of histograms and distributions to allow data analysis.

The first three and the last of the above programs are complete, and the fourth is in the final stages.

By requiring the occurrence of counts in both Cerenkov counters, one hydrogen and one water, and from range determination, we observe the momentum distribution of the electrons in a fraction of the data. Based on the sample and our total number of events, we can estimate that we will observe approximately several thousand K_{e3} decays. We also expect a thousand K_{e3} decays where one γ ray is observed, and several hundred events where both γ rays are observed. The data analysis will be continued in 1966.

K^+ DECAY-- $K_{\mu3}$

Ned Dairiki and others

Another objective for the Bevatron run is a measurement of the muon polarization from the $K_{\mu3}$ decay, as well as a measurement $K_{\mu3}$ muon momentum distribution. Data were recorded on magnetic tape by using an on-line PDP-5 computer and Vidicon digitizing system for the spark chambers. Stored information included counter, wire chamber, spark chamber, and K^+ lifetime data for each event.

The initial level of programs to scan and kinematically analyze the events is near completion, and the systematics of the experiment are presently under study. A combination manual scan and programmed kinematics analysis of an initial 10% of the data has been analyzed. Preliminary estimates include about a thousand events for a $K_{\mu3}$ polarization measurement, and several thousand events for a $K_{\mu3}$ muon-distribution measurement.

The analysis will proceed to correlate the polarization of the μ , the momentum of the μ , and the momentum and angle of the π^0 in combinations.

$\pi\alpha$ SCATTERING

Kenneth M. Crowe, Jaques Miller
and Anthony M. Fainberg

The pion form factor has been the object of a counter experiment using the 184-inch cyclotron's pion beam at 200 MeV/c. The principle outlined in a paper by Hofstadter and Sternheim is to look for the Coulomb interference effects in elastic $\pi^+\alpha$ scattering to determine the effective size of the $\pi\alpha$ system. By varying the momentum and angle, we are observing the difference

$$\frac{\sigma^- - \sigma^+}{1/2 (\sigma^- + \sigma^+)} \text{ vs } q_0^2.$$

At present the results will depend on a phase-shift analysis to extract the real part of the nuclear amplitude, rather than reliance on the theory of Sternheim. To date, the data are being improved statistically at 200 MeV/c and 150 MeV for angles between 30 and 140 deg. The analysis is being programmed for the computer.

Results have been reported by Nordberg (Rochester) and Block (Northwestern) which indicate approximate limits on the pion size. To get these, the helium size must be assumed to be known from the electron scattering data. The obtained accuracy on the pion size depends critically on the answer one obtains.

At this point, we know only that

(a) we have much higher data accuracy than has been reported by others

(b) the d waves are necessary to obtain reasonable fits,

(c) the imaginary phase shifts are not at all negligible,

(d) qualitatively, the interference is considerably smaller than predicted.

We plan to improve the accuracy of the results by using a magnetic spectrometer and a wire chamber detector system which is the spectrometer used in the previously discussed K^+ Bevatron run.

This program of research will be continued in fiscal year 1967.

PHYSICS RESEARCH: NUCLEAR EMULSION GROUP

Harry H. Heckman in charge

SPACE RESEARCH

Trapped Protons at Low Satellite Altitudes

Harry H. Heckman

(In cooperation with George H. Nakano),
(Lockheed, Palo Alto)

The program to study the properties and solar-cycle variations of energetic protons of the inner radiation belt is proceeding satisfactorily. During this report period, scanning effort was concentrated on proton energy-spectrum measurements, 58 to 500 MeV. No changes have been observed in the shape of the spectrum during the recent period of minimum solar activity. The spectra are in good agreement with those observed during the late stages of the previous solar cycle, 1959-1960.

The increase in the flux of protons at 65 MeV (by a factor ≈ 2) we observed in June 1965, and reported previously, still appears to be a valid measurement. The flux estimate was checked by rescanning. Not completely excluded, however, is the possibility of an error in the ephemeris data. Emulsion packets, recovered from two polar-orbiting satellites during the interval November 1965 to April 1966, will be used to extend this study on the temporal variations of trapped protons at low altitudes and their relation to solar activity and its 11-year cycle.

Apollo Earth-Orbital Experiment

Harry H. Heckman

An emulsion experiment is being prepared for Apollo mission 205 to study the trapped radiation over the South Atlantic anomaly. The experiment will be carried out in cooperation with the University of California Space Sciences Laboratory. The emulsion package, mounted on a simple probe, will be exposed outside the command module by use of a specially designed air lock. In order to increase signal-to-noise ratio by 10 to 20, the orbital altitude of the spacecraft will be changed from 140 to 260 n. mi. (nominal values) before the exposure takes place. At apogee over the South Atlantic, the spacecraft--i. e., emulsion--will be oriented with respect to the earth's (calculated) magnetic field vector, an operation that will incorporate the use

of the on-board computer. After six consecutive traversals of the South Atlantic anomaly, 15 minutes each for a total of 90 minutes, the orbital altitude will be lowered to 140 n. mi. The emulsion will be stowed in the command module for the remainder of the mission.

Higher-Order Terms in the Magnetic Moment
Adiabatic Invariant for Particle Motion
in a Dipole Magnetic Field

Harry H. Heckman

Following Northrop,¹ we have utilized the fact that the canonical angular momentum $p_\phi = \gamma m r v_\phi + e r A_\phi$ is a constant of the motion in order to express the magnetic moment adiabatic invariant series, through the second order, of a particle at the equatorial plane of a dipole magnetic field. The result is

$$C(\delta, \lambda) = \text{constant} = \cos^2 \delta [1 - 6\epsilon \sin \delta \sin \lambda + \frac{51}{2} \epsilon^2 \sin^2 \delta \sin^2 \lambda + \frac{3}{4} \epsilon^2 (1 - 8 \cos^2 \delta)], \quad (1)$$

where δ is the pitch angle of the particle, λ is the phase angle between the radius vector \underline{r} and $\underline{v} \sin \delta$, and $\epsilon = r_0/L$, the ratio of the gyroradius pc/eB_0 at the equator and the McIlwain shell parameter.

We have numerically integrated the equations of motion for a particle in a dipole field for representative values of ϵ , for the purpose of comparing the orbit calculations with Eq. (1). We find that for $\epsilon \lesssim 0.0176$, corresponding to protons of 125 MeV and less near the center of the inner radiation belt, $C(\delta, \lambda)$ increases nonrandomly, varying systematically with the parameter $\sin \delta$ and $\sin \lambda$. Particle motion is highly stable up to a proton energy of 1 BeV (at $L = 1.45$ earth radii). We shall therefore be able to evaluate empirically the coefficients of the linear and quadratic terms in $\sin \delta \sin \lambda$ Eq. (1).

1. The Adiabatic Motion of Charged Particles (Interscience Publishers, New York, 1963).

ENVIRONMENTAL EMULSION TESTS

John N. Dyer and Harry H. Heckman

The experiments subjecting G and K emulsions to temperatures ranging from -25° to $+100^{\circ}$ C have been extended to include subjecting emulsion stacks to those treatments for periods ranging from 24 hours down to 1 hour; the temperature at which fog begins to increase rapidly becomes higher as the heating time gets shorter. Even for heating for only 1 hour, however, K emulsions show a serious increase in fog at temperatures around 70° C and above.

Other experiments in which emulsions were heated at 55° C for periods greater than 1 week show that the fog background increases with time, reaching twice its normal value in about 1 week. At this temperature, however,

the fog never becomes so severe as it does at higher temperatures (70° C) even for short times.

Eradication experiments have been conducted on these heated emulsions. We find that the fog background is not eradicated so easily as the image of electron tracks. Furthermore, in G emulsions the eradication procedure is very ineffective. Therefore, the quality of the processed emulsion probably cannot be improved by eradicating the fog and leaving the tracks.

Measurements of the thermal conductivity and hardness of emulsions as a function of relative humidity are now under way. It is hoped that these will provide a quick method for estimating emulsion density.

PAPERS AND PUBLICATIONS

Papers Delivered

G. H. Nakano and H. H. Heckman, Trapped Protons in the South Atlantic Anomaly, presented at 47th Annual Meeting of American Geophysical Union, Washington, D. C., April 19-22, 1966.

I. B. Strong, J. R. Asbridge, S. J. Bame, H. H. Heckman, and A. J. Hundhausen, Correlation between Measurements of Solar Wind Velocity and Temperature, presented at 47th Annual Meeting of American Geophysical Union, Washington, D. C., April 19-22, 1966.

Journal Articles

I. B. Strong, J. R. Asbridge, S. J. Bame, H. H. Heckman, and A. J. Hundhausen, Measurements of Proton Temperatures in the Solar Wind, *Phys. Rev. Letters* 16, 631 (1966).

Harry H. Heckman and Victor O. Brady, Effective Atmospheric Losses for 125-MeV Protons in South Atlantic Anomaly (UCRL-16592, Dec. 1965), *J. Geophys. Res.* (to be published).

THEORETICAL PHYSICS DIVISION

David L. Judd

October 1965 - April 1966

I. S-MATRIX THEORY

In the construction of S-matrix theory from fundamental axioms, the crossing principle has been formerly assumed as a postulate. A derivation of the crossing property from other axioms has now been carried out. Also derived is the important Hermitian analyticity relationship, which is the relationship that converts the unitarity equation into the fundamental discontinuity equation needed for dispersion relations. In the course of the work a new S-matrix proof of the normal connection between spin and statistics has been obtained. The new proof does not depend on an objectionable special assumption used in an earlier S-matrix proof, or on the notion of interchange of variables describing nonidentical particles. The work is being prepared for publication.¹ (Henry P. Stapp)

An asymptotic causality condition has been formulated within the S-matrix framework. On the basis of this causality condition, it has been proved that the connected part of the scattering amplitude is analytic in the physical region except for possible singularities on Landau surfaces. Moreover, these singularities are confined to the positive- a portions of the Landau surfaces. Thus the regions in which singularities are permitted by the causality condition are precisely the regions where the corresponding Feynman integrals are singular. The general $i\epsilon$ prescription for analytic continuation around any physical region singularity

has also been derived. The work is being prepared for publication. (Colston Chandler and Henry P. Stapp)

In the extension of S-matrix theory to multiparticle processes one needs discontinuity formulas for all the cuts bounding the physical sheet. Formulas believed to hold generally have been constructed and their self-consistency checked. They have been derived from unitarity in various special cases and work is progressing on a general derivation. (Joseph Coster)

An investigation has been made of the "cross-discontinuity condition" in S-matrix theory.² This assumption, which has been used by other authors in work on discontinuity formulae, states that the terms in a unitarity equation associated with a normal threshold discontinuity in one channel have no normal threshold singularities in overlapping crossed channels. It has been proved, by using S-matrix theory, that this assumption, although true in simple cases, is generally true only if the particles in the intermediate state are sufficiently near threshold. These results are being extended to show in general where a function may have singularities arising from the contraction of lines representing particles constrained to their mass shells. A study is also being made of second-type (non-Landau) singularities, in an attempt to show whether or not they can appear on the physical sheet. (David Branson, Harkness Fellow of the Commonwealth Fund)

1. Henry P. Stapp, Crossing, Hermitian Analyticity, and the Connection Between Spin and Statistics, UCRL-16816, April 1966 (to be submitted for publication).

2. David Branson, The Cross-Discontinuity Condition in S-Matrix Theory, Nuovo Cimento (to be published).

II. MASS-SHELL DYNAMICAL CALCULATIONS

The Mandelstam iteration has been analyzed for a strip model of the four-line connected part that conforms to most known strong-interactions experimental requirements at both high and low energies.³ It has been shown that, with the Froissart⁴ limit as a supplementary condition, the asymptotic behavior is controlled by Regge poles, the amplitude being meromorphic in the right-half complex angular momentum plane. Those results support the practicality of the Mandelstam iteration as a numerical technique for realistic bootstrap computations. (Naren F. Bali,* Geoffrey F. Chew, and Shu-Yuan Chu)

A computer program has been written to carry out the Mandelstam iteration in the single-channel equal-mass spinless case.⁴ Comparison with known potential (nonrelativistic) problems shows that the program is sufficiently accurate to perform such calculations reliably. Preliminary calculations of single-channel π - π scattering with an elementary ρ potential have been performed. Work is in progress to construct more realistic Reggeized potentials for the π - π problem. (Naren F. Bali)

The calculation of the $\pi\pi$, $K\bar{K}$ coupled two-channel scattering amplitude with Reggeized ρ , P , K^* , and ϕ exchange as the generalized potentials has been completed. The effect of the inelastic channel $K\bar{K}$ on the elastic $\pi\pi$ scattering amplitude is found to be not very important. (Naren F. Bali and Shu-Yuan Chu)

In the past, the angular distributions of $\pi^-p \rightarrow \pi^0n$ near the forward direction at high energy have been analyzed by various authors in terms of the ρ -trajectory exchange. With the collaboration of R. J. N. Phillips, W. Rarita, and F. Arbab, this work is being extended. Based on the recent Saclay-Orsay data with pion incident lab momenta between 6 and 18 GeV/c, an improved solution

has been obtained.⁵ Its features are as follows. In the region $|t| < 1.0 \text{ GeV/c}^2$, the trajectory is essentially linear with $\alpha(t) = 0.57 + 1.0 t$. The helicity-flip amplitude is large. The dip observed in the angular distributions at $t \approx -0.6 \text{ (GeV/c)}^2$ is caused by the ρ trajectory's passing through zero. The residue function of the non-helicity-flip amplitude passes through zero near $t = -0.2 \text{ (GeV/c)}^2$. The extrapolated residue functions at ρ resonance are consistent with our present knowledge of the nucleon electromagnetic structure. The polarization data for π^-p elastic scattering near the forward direction at 6 to 10 GeV/c are also being analyzed with the Regge model. Several solutions have been obtained. All of them predict that the π^+p polarization at the corresponding energy and momentum transfer region should be with an opposite sign. The $\pi^\pm p$ differential cross sections near the backward direction between 4 and 8 GeV/c is also being analyzed. The observed dip in the π^+p angular distributions near $u = -0.2 \text{ (GeV/c)}^2$ and the relatively smooth behavior in π^-p distributions have been shown to be consistent with the Regge hypothesis. (Charles Chiu)

The differential cross section for the high-energy $\pi N \rightarrow \omega N$ interaction has been calculated with the Regge-pole model, considering only ρ exchange. The ρ trajectory was obtained by fitting the energy dependence of the high-energy $\pi^-p \rightarrow \pi^0n$ differential cross section. The best fit obtained by Arbab and Chiu vanishes at $t \approx -0.6 \text{ (GeV/c)}^2$. The calculated $d\sigma/dt(\pi N \rightarrow \omega N)$ contains a factor of a^2 and thus has a minimum at $t \approx -0.6 \text{ (GeV/c)}^2$.⁶ Up to now there are no high-energy experimental data on $\pi N \rightarrow \omega N$. Therefore, this predicted minimum will constitute a test of the Regge-pole model.⁶ Calculations and comparisons with experiments are in progress for the interactions $\pi N \rightarrow \pi N^*$. (Ling-Lie Wang)

Hypercharge exchange processes, such as $K^-p \rightarrow \Lambda^0\pi^0$, are being analyzed by using Regge-pole formalism. Dr. Rarita's program for charge exchange is being adapted towards

3. Naren F. Bali, Geoffrey F. Chew, and Shu-Yuan Chu, Mandelstam Iteration in a Realistic Bootstrap Model of the Strong-Interaction S Matrix, UCRL-16774, April 1, 1966 (to be submitted to Phys. Rev.).

4. Naren F. Bali, Single-Channel Calculation of $\pi\pi$ Scattering Using the Mandelstam Iteration, UCRL-16775, March 21, 1966 (to be submitted to Phys. Rev.).

* Fellow of the Consejo Nacional de Investigaciones Científicas y Técnicas, Argentina.

5. Part of this work appears in Farzam Arbab and Charles B. Chiu, Association Between the Dip in the $\pi^-p \rightarrow \pi^0n$ High-Energy Angular Distributions and the Zero of the Regge-Trajectory (UCRL-16686, Jan. 27, 1966) submitted to Phys. Rev.

6. Ling-Lie Wang, Phys. Rev. Letters 16, 756 (1966).

this end. It is hoped that the parameters obtained will check with those obtained theoretically by Jerome Finkelstein.⁷ (Abraham Bookstein)

The reaction of pionic disintegration of the deuteron has been studied in the framework of the Regge-pole exchange formalism. Work is still in progress on the problem of the anomalous threshold singularity structure associated with the amplitude. (Huan Lee)

The equal spacing of the masses of the $J = 3/2$, $I = 3/2$ baryon resonances is being studied in a single baryon exchange model of pseudoscalar-meson octet and baryon octet scattering. The object is to learn whether an octet symmetry breaking of the meson-baryon coupling constants can destroy the equal spacing rule. All baryon-meson channels communicating with each set of quantum numbers are included (e.g., the Y_1^* is a five-channel calculation). Within the context of the model and its approximations, it was found that the equal spacing of the decuplet masses is remarkably stable under octet symmetry breaking of the meson-baryon coupling constants. Work is now in progress to examine the accuracy of expansions in mass- and coupling-constant perturbations. (Richard Slansky)

The analytic continuation of the partial-wave projection formula of D. Wong to the nearby left-hand cuts of the energy plane of the pion-nucleon system has been studied. Approximations to the crossed-channel amplitude contributions in these regions are being sought. (Andres A. Garcia*)

The asymmetry of the π^+ , π^- energy spectra in η and $X \rightarrow \pi^+\pi^-\gamma$ decays caused by a C nonconservation in electromagnetic interactions has been analyzed,⁸ with the assumption that the P- and D-wave pion-pion phase shifts satisfy an effective range expansion whose parameters are determined by the position and width of the ρ^0 and f resonances. (Barbara Barrett)

A previously begun study was completed in which S-matrix perturbation theory was used to estimate the ρ -meson electromagnetic mass splitting; the prediction is $M_{\rho^0} - M_{\rho^+} \approx 13$ MeV, which should be observable in the near future. The $K_2^0 - K_1^0$ mass difference was also considered with these techniques.

* Fellow of Aid and CNEA, Argentina.

7. Jerome Finkelstein, Equivalent-Potential Calculation of $\pi\pi$ and πK Scattering, UCRL-16537, Nov. 24, 1965.

8. Barbara Barrett and Tran N. Truong, Analysis of η^0 , $X^0 \rightarrow \pi^+\pi^-\gamma$ With a Possible C Violation, submitted to Phys. Rev.

Crude dynamical models could give only a rough estimate of the magnitude of the mass difference, but definitely implied a heavier K_2^0 , in agreement with recent experiments. The relevance of the πN^* channel for an S-matrix calculation of the neutron-proton mass difference is being studied currently. The aim is to see if any drastic modification of a previous πN -channel calculation will occur. (Douglas S. Beder)

In a brief study, arguments and a plausible model were developed to support the idea that an infinite number of coupled channels could lead, asymptotically, to purely imaginary partial-wave amplitudes and vanishing form factors.¹⁰ This study was intended to illustrate the compatibility of current dispersion techniques with these conjectured high-energy features. (Douglas S. Beder)

The assumption that photon matrix elements are dominated by vector meson states was used to relate meson photoproduction and strong production of vector mesons. Use of experimental data for the latter reaction provides photoproduction predictions which seem to be consistent with present data.¹¹ (Douglas S. Beder)

Theoretical studies of meson-production interference effects were carried out in collaboration with a CalTech experimental group for an experiment to be run at LRL next year. The general form of ρ - ω interference effects was elucidated and a possible method was suggested for predicting lepton-pair-production interference effects in terms of analysis of π - π production data. (Douglas S. Beder)

The solutions of certain N/D equations were investigated, with especial emphasis on the marginally singular case.¹² The conditions for, and some implications of, the occurrence of extinct bound states in a scattering

9. Douglas S. Beder, the ρ -Meson Electromagnetic Mass Splitting, UCRL-16465, Oct. 13, 1965; The $K_1^0 - K_2^0$ Mass Difference in S-Matrix Theory, UCRL-16474, Oct. 19, 1965; and Meson-Photon Channels and the Electromagnetic Mass Difference, UCRL-16333, Nov. 22, 1965.

10. Douglas S. Beder, Diffraction Scattering and Form Factors, UCRL-16728, Feb. 28, 1966.

11. Douglas S. Beder, Vector Dominance and Meson Photoproduction, UCRL-16781, March 28, 1966.

12. D. Atkinson, The Existence of Solutions of N/D Equations, J. Math. Phys., to be published.

process were discussed.¹³ On the basis of the crank-shaft analysis of an SU(6) model, CDD poles were found in both the P_{11} and P_{33} waves of πN scattering. These results may facilitate, on the one hand, an understanding of certain known properties of P_{11} and P_{33} , and on the

other, an explanation of the many failures to obtain these waves dynamically. CDD poles arose in pseudoscalar meson-meson scattering, in conjunction with a conjectured SU(3) nonet of extinct bound states.¹⁴ (David Atkinson, University of California Physics Department)

13. D. Atkinson and M. B. Halpern, On the Dynamical Calculation of Extinct Bound States, submitted to Phys. Rev.

14. D. Atkinson and M. B. Halpern, Possible One-Channel CDD Poles in πN and $\pi\pi$ Scattering, submitted to Phys. Rev.

III. OFF-MASS-SHELL DYNAMICAL CALCULATIONS

Recently Baláz's¹⁵ has presented a new method for studying the dynamics of strongly interacting particles. The essential idea is to construct an "equivalent potential" which, when fed into a Schrödinger equation, generates a unitary, relativistic scattering amplitude. The construction of the potential has been carried out by Baláz's for the equal-mass case when a single pole in momentum transfer is assumed to dominate the Born approximation. The resulting configuration-space potential agrees in essence with the potential calculated by using the Chew¹⁶-Frautschi prescription; i. e., the range of the force due to the exchange of a particle of mass M_p is $1/M_p$ and is energy-independent. The analogous calculation for unequal masses has been reported incorrectly for N exchange in πN scattering¹⁷ and for K^* exchange in πK scattering¹⁸. We correct these mistakes¹⁹ and investigate the consequences of them. (Michael DerSarkissian)

Calculations of the $\pi\pi$ and the πK scattering amplitudes by means of an energy-dependent potential constructed so as to insure both elastic unitarity and the correct Born term have been continued.¹⁸ This method has been extended to include scattering problems with several coupled channels, and used to calculate coupled $\pi\pi$ and $K\bar{K}$ scattering, with the Born term provided by SU₃-symmetric vector meson exchange. Also, a program to calculate the πN amplitude has been begun. (Jerome Finkelstein)

15. Louis A. P. Baláz's, Phys. Rev. 137, B1510 (1965).

16. G. F. Chew and S. Frautschi, Phys. Rev. Letters 5, 580 (1960).

17. Louis A. P. Baláz's, Phys. Rev. 139, B1646 (1965).

18. Jerome Finkelstein, Equivalent Potential Calculation of $\pi\pi$ and πK Scattering (UCRL-16537, Dec. 1965) Phys. Rev., to be published.

19. M. DerSarkissian, for Scattering by Particles of Unequal Mass, UCRL-16748, March 7, 1966.

The Raleigh-Ritz variational method is being used to find approximate solutions of the Euclidean Bethe-Salpeter equation for two spin-zero particles of masses m_1 and m_2 . The ladder approximation with potentials arising from single-particle and (singular) di-particle exchange is used. The preliminary results are in good agreement with the available exact solutions in the case in which both the exchange mass and the total energy are zero. (William B. Kaufmann)

A variational calculation of the bound states of the pion-nucleon system using the Bethe-Salpeter equation is in progress. Certain difficulties inherent in both the bound state and the scattering problem are studied in this simpler context. Once these difficulties are understood we will return to the pion-nucleon scattering problem.²⁰ (Klaus D. Rothe)

Separable approximations to off-energy-shell two-body transition amplitudes, which are needed in multiparticle scattering calculations, have been investigated. Special attention has been paid to nonlocal, separable potential forms which lead to scattering amplitudes with analyticity properties very similar to those obtained in local potential theory.²¹ Work is in progress on the problem of obtaining a separable approximation to the nucleon-nucleon scattering amplitude which will incorporate some features of the one-boson exchange model. (Thomas R. Mongan)

The off-mass-shell Bethe-Salpeter equation is being studied for the purpose of finding a better potential for the on-mass-shell equation in a crossed channel. One needs first to solve the equation for the "Wick rotated" total momentum vector. It was noticed that if one "Wick rotates" all momentum vectors, the

20. See Physics Division Semiannual Report, UCRL-16511, Nov. 1965, p. 15.

21. Thomas R. Mongan, Separable Two-Body Potentials for Multiparticle Scattering, Phys. Rev. (to be published).

equation can be solved by using the Kohn variational principle, instead of the more complex Schwinger variational principle used by Schwartz and Zemach.²² We are now in the process of solving the equation by the Kohn method. When this is completed we shall try to continue our solutions back to the physical energy region. (Richard Haymaker)

The conditions imposed on the π^+ -p elastic amplitude by the competing process of pion production are being investigated, by means of a statistical model, to find what form of the elastic amplitude is consistent with the elastic differential cross-section data for low momentum transfer and high energy. (Judith Binstock)

22. Charles Schwartz and Charles Zemach, *Phys. Rev.* **141**, 1454 (1966).

Work directed to finding accurate approximate calculations for atomic rearrangement collisions at intermediate energies has been completed. The conclusion drawn from the work on a mockup of an ion-atom system undergoing single charge exchange is that the dominant effect can be accurately described by approximation schemes that explicitly incorporate asymptotic boundary conditions. The interpretation of the approximation schemes is that the main part of the physical process may be characterized, as a repeated exchange of the charged particle between the two relatively moving parts of the scattering system. (James Quong)

23. James Quong, *Approximations in Rearrangement Collisions and Applications to a Tractable Model of Atomic Charge Exchange Scattering*, Ph. D. thesis (in preparation).

IV. THEORY OF LEVEL SHIFTS AND LINE WIDTHS

A study (in collaboration with F. Goldhaber) is being made of pi-mesic atomic level shifts and line widths. Part of this work is concerned with the general theory of lifetime and decay for a cascade process. The remainder of the study is concerned with obtaining numerical estimates of the shift and width. (Kenneth Watson)

An investigation of interference effects associated with the radiative decay of coherently excited nondegenerate atomic states has been completed. The Goldberger-Watson wave-packet formulation of scattering theory has been used to analyze quantum-beat and level-crossing experiments.²⁴ Work is in progress on intensity-correlation effects in the inelastic scattering of neutrons by solids and on the electrooptic effect in ionic crystals.²⁵ (Robert Kelly)

The relationship of partial rates to the fundamental processes contributing to the absorption line shape has been analyzed in some special cases in which broadening in the lower state of the atom is unimportant. To treat the more general case, a graph-by-graph cutting scheme is necessary. This possibility is being studied. A complete theory of line broadening

has been developed with special emphasis placed on collective effects. This formalism is being applied to the problem of resonance or self-broadening. In this work the role of resonance transfer of the excitation is described, and the validity of the simple impact theory is investigated. (Bandel Bezzarides)

The amplitude and the intensity correlations of photons from a model thermal source have been studied.²⁶ The model source is analyzed by utilizing the temperature Green's-function method. The power spectrum is computed numerically for some special cases. General properties of temperature Green's functions are also studied. (Shang-keng Ma)

A study of the shifts and widths induced in the Coulomb energy levels of pi-mesic atoms by the pion-nucleus interaction has entered the data-analysis phase. A Fortran program has been written to evaluate the complex level shifts due to a nuclear interaction represented by a complex square well for both the local potential and the effective mass. The well depths for both potential and effective mass are allowed to depend on the three-component of the nuclear isotopic spin. The level shifts are found to be very sensitive to the effective mass parameter in the region of large effective mass. Theoretical predictions based on pion-nucleon scattering lengths imply that the effective mass should be large. A pre-

24. Robert Kelly, *Theory of Quantum-Beat and Level-Crossing Experiments Utilizing Electronic Excitation*, *Phys. Rev.* (to be published).

25. Robert Kelly, *The Linear Electro-Optic Effect in Zincblende Structure Ionic Crystals*, General Motors Research Publication GMR-514, Dec. 1965 (unpublished).

26. Shang-keng Ma, *Correlation of Photons from a Thermal Source* (Ph. D. thesis), UCRL-16824, April 27, 1966.

liminary fit to data obtained from experiments at the 184-inch cyclotron by the Crowe group also indicates that the effective-mass param-

eter is large. Further data analysis and refinements of the model are in progress. (Tom Mottershead)

V. FIELD THEORY

The algebra of current commutators, derived by means of a quark model, has been studied by employing a dispersive technique. Matrix elements of the algebra between nucleon states leads to exact sum rules. In the approximation of keeping only the octet of nucleons and the decuplet of baryon resources as intermediate states, one obtains the results of SU(6)W.²⁷ (Gino Segrè)

The significance of a general relation between the integral over energy of the discontinuity of a scattering amplitude and form factors derived from the algebra of current commutators has been explored. It was shown that the high-energy behavior of the scattering amplitude generates the singularities of the form factors. Several applications were given.²⁸ (Gino Segrè)

The diagram examined originally by Amati, Fubini, and Stanghellini--which, in the elastic unitarity approximation, gave rise to cuts in the angular momentum plane--and also a simpler version of that graph, involving single Regge-pole exchange together with an elementary exchange, have been examined once again from the Feynman point of view. Besides arriving at the conclusion, reached via a different approach by Mandelstam, that the cuts are absent in the full diagram, we have succeeded in revealing the extreme simplicity of the cancellation mechanism itself. That is, we have shown explicitly how the inelastic contributions to the unitarity relation manage to exactly cancel the above-mentioned cut. The mechanism found suggests very strongly that the cuts should be present in more complicated diagrams, as was already found by Mandelstam and Wilkin. In addition, we have analyzed in detail the singularity structure of the partial-wave amplitudes, $c(\ell, s)$, in the angular momentum plane. In particular, for the single Regge-pole exchange diagram, we were able to obtain an explicit expression for the function $c(\ell, s)$. This allowed us to confirm the conclu-

sions we had reached by studying the full diagram in its integral representation. (Heinz J. Rothe)

Five years ago K. Johnson exhibited a structural inconsistency in the equations of the minimal quantum electrodynamics of charged spin-3/2 fields: the conventional anticommutative algebra of the fermion field components is internally consistent. We have located a similar phenomenon in the minimal quantum electrodynamics of boson fields of spin >1; here, certain vacuum expectation values which should (for consistency) be positive definitely are not. A possibility not considered by Johnson--that of the possible consistency of spin-3/2 quantum electrodynamics with an intrinsic moment--has been explicitly computed and rejected. Work is in progress on the structure of the spin-2 theory and the higher spin generalizations of these theorems. (Mark F. Sharefkin)

The final form of a thesis concerning infrared divergences was completed.²⁹ A description of this work appeared in the preceding semiannual report. (Victor Chung)

Connections between Regge poles and elementary particle poles have been studied earlier.^{30, 31} Those works were restricted by the assumption of two-particle multichannel unitarity. Now it has been shown, without any approximation, that if the renormalized pion-nucleon proper vertex function with one nucleon off the mass shell vanishes, then the elementary nucleon lies on the Regge trajectory, and all Castillejo-Dalitz-Dyson's zeros disappear. From this condition it also follows that $Z_1 = Z_2 = Z_2 \delta M = 0$, where Z_1 is the vertex-renormalization constant, Z_2 is the nucleon wave-function renormalization constant,

27. S. Fubini, G. Segrè, and J. D. Walecka, Dispersion Relations and Higher Symmetries, Ann. Phys. (to be published).

28. Sergio Fubini and Gino Segrè, Nonforward Dispersion Relations and the Algebra of Current Commutators (UCRL-16755, March 8, 1966) Nuovo Cimento (to be published).

29. Victor Chung, Infrared Divergences in Quantum Electrodynamics (Ph. D. thesis), UCRL-16808, March 15, 1966.

30. Takesi Saito, Connection Between Regge Poles and Elementary-Particle Poles (UCRL-16544, Nov. 1965) Phys. Rev. (to be published).

31. Takesi Saito, Unsubtracted Dispersion Relations in Weak Interactions and Reggeization (UCRL-16628, Jan. 1966) Phys. Rev. (to be published).

and δM is the nucleon self-mass. But the converse of this is not always true, i. e., the vanishing of the vertex function does not generally follow from $Z_1 = Z_2 = Z_2 \delta M = 0$.

Therefore, the widely recognized compositeness condition, $Z_1 = Z_2 = 0$, or $Z_2 = Z_2 \delta M = 0$, is not sufficient to Reggeize the elementary nucleon. (Takesi Saito)

VI. NUCLEAR PHYSICS

An investigation of the effect of curvature on the nuclear surface energy has led us to a more general problem, namely an attempt to obtain an adequate description of the average properties of nuclei. To this end a statistical treatment of nuclei, analogous to the "Thomas-Fermi" treatment of atoms, has been developed. A combination of the Fermi-gas expression for the kinetic energy of the nucleus, and of the Klein-Gordon equation (which replaces the Poisson equation of the atomic case) leads to a differential equation for the density distribution in nuclei analogous to the Thomas-Fermi atomic equation. Nuclear saturation is achieved by a combination of two effects. On the one hand, in order to simulate exchange effects, the strength of the attractive nuclear forces is assumed to be a decreasing (phenomenological) function of nuclear density. On the other hand, in analogy with a Van der Waals treatment of gases, the kinetic energy is assumed to be modified by a term which takes into account the "excluded volume" associated with repulsive hard-core interactions. The resulting differential equation was found to have surprisingly simple approximate solutions, which can be used to study average properties of nuclei such as the surface energy and thickness, the functional form of the density fall-off across the surface, the value of the nuclear compressibility coefficient, the curvature correction, etc. It is hoped that this treatment will prove to be as useful for nuclei as the Thomas-Fermi equation has been for atomic and molecular problems. (W. D. Myers and W. J. Swiatecki)

The attempt to understand the physical origin of the "Wigner term" in nuclear mass formulae (especially strong binding of nuclei with approximately equal neutron and proton numbers) has been only partly successful. By use of a model of neutron and proton Fermi gases in a rectangular box interacting by short-range forces, an effect qualitatively like the Wigner term has been found: it is associated with the especially good overlap of the neutron and proton wave functions for identical orbitals. Some progress was made in a study of the dependence of the term on the neutron excess and on the shape of the box, but a final understanding of the effect has not been achieved. A more general calculation has been started in which the total kinetic and potential energies of particles in a box will be analyzed in terms of an expansion in the ratio of the spacing between the particles to the size of the box (i. e., an expansion in powers of $A^{-1/3}$, of which the leading terms are volume, surface, and curvature energies). The attempt is to make use of the rectangular box with its simple geometry and wave functions as a model of a nucleus. On the one hand, this model may be used to study interaction effects such as the surface energy, the symmetric energy, and the Wigner term, which might be harder to analyze in a more realistic nuclear model. On the other hand, it will act as a test for approximation techniques which may be developed to treat these effects. (W. J. Swiatecki and Chin-Fu Tsang)

VII. MANY-PARTICLE SYSTEMS

A thesis³² on the properties of liquid He^3 was prepared for publication.³³ First, the two-body correlation approximation was specified and then the equations appropriate to the approximation derived. This formalism is now being employed in a continuation (by D. E. B.) of the present work. The second part of the thesis is devoted to an approximate calculation employing separable potentials and a noniterated interaction matrix. This is interesting because of the resulting spectral functions, which are not δ functions, as in all previous studies. Numerical comparisons are given with the experimental properties of liquid

helium. [Donald Beck (U. C. S. D.) and Andrew M. Sessler]

32. Donald E. Beck, A. Quantum Statistical Calculation of the Properties of Liquid-Helium-Three (Ph. D. thesis), UCRL-11679, Sept. 1964.

33. Donald E. Beck and Andrew M. Sessler, Properties of Liquid Helium-Three in the Two-Body Correlation Approximation, I (UCRL-16524, Nov. 1965) Phys. Rev. (to be published).

The computation described in the preceding annual report, directed toward determining the ground-state energy, E_0 , and the effective mass, m^* , of the polaron, was completed. It was possible to determine the ground-state energy for an important but restricted range of coupling strengths, including most of the so-called intermediate-coupling region. These upper bounds on the energy, E_0 , were generally lower than results of other variational computations for coupling strengths less than $\alpha \approx 7$. It was possible to estimate the error in these results; the estimated fractional error varied from 0.1% (weaker coupling) to 1.0%. The possibility of making error estimates gives, effectively, an approximate lower bound on the energy, an advantage not shared by previous computations. The effective mass, m^* , was determined for the same range of coupling strengths. The accuracy of these results was more difficult to estimate, because they do not have the characteristic of being a bound (e.g., upper bound), and because of numerical considerations. A comparison of our results with those of Feynman (obtained by use of his path-integral formalism) shows that Feynman's results are close to our own for $\alpha = 7$, and Feynman's upper bounds are in fact lower for stronger coupling. This comparison may be regarded as surprising because of the relatively greater simplicity (from the computational point of view) of Feynman's approach.³⁴ (Walter Zimmermann)

34. Walter Zimmermann, *The Numerical Solution of the Problem of a Slow Conduction Electron in an Ionic Crystal* (Ph. D. thesis), June 1966.

A transport theory for dilute polyatomic gases is being developed by use of the multiple scattering techniques developed by Watson³⁵ and others. The aim is to account for quantum effects in the form of corrections to the semiclassical equations derived by Wang-Chang and Uhlenbeck. A test-particle approach is being used whose Wigner function will be constructed from the full system wave function. The change of the Wigner function due to a single collision can be obtained, leading to a generalization of the Liouville equation. The treatment is analogous to that of Mori et al.³⁶ (Warren Wollman)

35. K. M. Watson (with M. L. Goldberger), *Collision Theory* (John Wiley and Sons, New York, 1965).

36. Mori, Oppenheim, and Ross, *Studies in Statistical Mechanics*, v. II (North-Holland Publishing Co., Amsterdam, 1964).

A kinetic equation for a homogeneous field-free plasma has been derived. This equation effectively joins the theory for a stable sys-

tem (the Lenard-Balescu equation) and that for an unstable system (the quasilinear equation), for it contains terms from each equation, plus a term rather similar to that of quasilinear theory, but depending only on the one-particle distribution function. The derivation follows the formal methods of Dupree, except that the collision term is evaluated for finite time, rather than in the limit $t \rightarrow \infty$. The behavior of a large number of terms which appear to oscillate in time is obtained by analytic continuation of various integrals in a manner similar to that used by Landau. We show that the kinetic equation satisfies the conservation laws, leads to an H theorem, and correctly reduces to the Lenard-Balescu equation in the asymptotic (long time) limit. We then generalize the equation to include the effect of a uniform magnetic field. (John C. Price)

A collision term valid to order $1/\ln \Lambda$ for small-amplitude waves in a uniform plasma is obtained. This result generalizes the ordinary Fokker-Planck equation from the domain $0 \leq \omega \ll \omega_p$, $0 \leq k \ll k_d$ to the domain $0 \leq \omega \ll \omega_p$, $0 \leq k \ll k_d$. We show that the collisional correction to the behavior of small-amplitude waves also appears in the description of fluctuations in a spatially uniform plasma. This correction applies to the kinetic equation described above, so that the collective effects arising from zeros of the dielectric function are affected by collisional damping as well as by Landau damping.

The convergent plasma kinetic equation of Guernsey³⁷ has been generalized by a quantum mechanical treatment to include the temperature regime $kT \geq \text{Ryd}$ as well as the classical regime $kT \ll \text{Ryd}$. Static transport coefficients are being obtained by using the Chapman Enskog technique to solve the kinetic equation. The collision integrals for the short range part of the interaction are being evaluated using a phase shift analysis.³⁸ The results for $kT \gg \text{Ryd}$ are in agreement with calculations from the quantum mechanical Lenard-Balescu equation, while for $kT \ll \text{Ryd}$ the results agree with the classical calculations of Gould.³⁹ (R. H. Williams)

37. R. L. Guernsey, *Phys. Fluids* 7, 1600 (1964).

38. R. H. Williams and H. E. DeWitt, *Quantum Mechanical Treatment of Close Collisions in Plasma Transport Theory*, UCRL-16634, Jan. 1966.

39. Harvey A. Gould, *Use of the Bethe-Salpeter Equation in Transport Theory and the Derivation of a Convergent Kinetic Equation for a Classical Plasma* (Ph. D. thesis), UCRL-16557, Nov. 23, 1965.

The conductivity of a classical plasma has been calculated without the use of any ad hoc cutoffs. Some conjectures have been made on a relation between high-frequency and static transport coefficients, but so far no results have been obtained. (Harvey Gould)

The study of Bose systems confined to a film geometry has been continued. Numerical analysis on the ideal Bose gas model was completed. The Bogoliubov model was shown to exhibit macroscopic occupation and a first-order transition. The Ginzburg-Pitaevskii theory was shown to yield only second-order transitions. Finally, a variational principle for the self-energy is being used in the Born approximation for further study of restricted geometries. (Victor K. Wong)

The theory of spontaneous aurora was proposed in connection with the interchange instability occurring at the outer boundary of the Van Allen belts lying at about eight earth

radii. This theory attempts to explain the nightly spontaneous occurrence of aurora not externally triggered by magnetic storms. The outer boundary of the Van Allen belt is energetically unstable⁴⁰ but is stabilized during the day by the high ionospheric conductivity.⁴¹ Thus, the instability occurs spontaneously only at night and causes the precipitation of energetic particles to the aurora zone. The energy flux of these particles gives roughly the observed intensity for the aurora. Furthermore it explains the corotation of the aurora rays with the earth and the associated uplifting of F₂ layer. (C. S. Liu)

40. T. Gold, *J. Geophys. Res.* 64, 1219 (1959).

41. D. B. Chang, L. D. Peralstein, and M. N. Rosenbluth, *J. Geophys. Res.* 70, 3085 (1965).

VIII. GRAVITATIONAL STUDIES

The Einstein equations of general relativity for the spherically symmetric case are being applied to the analysis of certain models of stars, with certain assumption being made about such things as the pressure, density, charge density, and electromagnetic field. One method for analyzing these models is to make an assumption about the metric tensor and then determine whether the physical quantities (e. g., pressure, etc.) derived from it are physically possible. In addition to analyzing internal properties of ordinary stars, this method might also explain some of the properties of so-called "quasars," which have recently evoked much discussion among astrophysicists. (Peter J. A. Gaposchkin)

Recent radar observations and a reinterpretation of earlier visual data have suggested that the planet Mercury does not, as was long thought, rotate synchronously with its orbital motion, but has a rotational period close to two-thirds of the orbital value. The possibility of stable rotational modes for which the rotation period is a simple rational fraction of the orbital period has been investigated analytically for a planet moving in an eccentric orbit and for which the moments of inertia about axes in the equatorial plane are not exactly equal.

Such stable modes are formally analogous to the stable "buckets" for longitudinal motion in particle accelerators. It was shown in particular that resonance lock in the two-thirds mode is possible, and a simple formula was derived for the period with which the instantaneous rotation period may make small-amplitude oscillations about the locked-in value. These results, reported by L. Jackson Laslett and Andrew M. Sessler, *Rotation of Mercury: Theoretical Analysis of the Dynamics of a Rigid Ellipsoidal Planet*, have been published in *Science*. (L. Jackson Laslett and Andrew M. Sessler)

Recent published articles have indicated an interest in the trajectory for minimum transit time between two points on the earth's surface by frictionless gravitational fall through a tube that provides an optimum trajectory through the earth. A variational equation for this optimum path has been derived and an integral obtained to give explicitly the equation for θ as a function of r along the path. This result is reported by L. Jackson Laslett, *Trajectory for Minimum Transit Time Through the Earth* (UCRL-16674, Jan. 1966), and has been accepted for publication in *American Journal of Physics*. (L. Jackson Laslett)

IX. ACCELERATOR DESIGN AND ELECTROMAGNETIC THEORY

Members of the Theoretical Group have continued to contribute to the LRL Design Study for a 200-BeV alternating-gradient proton synchrotron. A considerable portion of the theoretical effort has involved a review of the present technical plans, and assistance to groups responsible for the design of specific components of the projected accelerator. In addition, specialized work has been directed to a computational investigation of alternative injection methods, to continued study of means for closed-orbit control, and to seeking further insight into self-consistent solutions for the envelope of a beam subject to space-charge forces in an alternating-gradient structure.

The injector studies (Alper Garren) have focused on a type of four-beam synchrotron that might be suitable as a component of the 200-BeV facility, or as an injector for the improved AGS or CERN PS. The concept represents a generalization of W. Hardt's two-beam TART device (Twin Accelerator Ring Transfer), and is analogously named the QUART. The QUART consists of two concentric rings of gradient magnets arranged in pairs, with one magnet of each pair situated on the outer ring and one on the inner. Members of a given pair are either both focusing or both defocusing, and the sign of the focal power alternates from one pair to the next. By designing the outer magnets to have three times the length, one-fourth the gradient, and the same field as the inner magnets, four beams that pass successively through two outer magnets and two inner magnets can be simultaneously accommodated. In practice the QUART would have one-fourth the effective circumference of the accelerator into which these beams would be injected in succession, so that complete filling would be achieved and bunch-to-bunch synchronization would be possible.

The chief advantages of the QUART are believed to reside in (i) its ability to present the same space-charge limit for each of its four beams as would a conventional synchrotron of the same energy and beam quality, and (ii) the combined features of relatively small size, reasonable aperture, bunch-to-bunch ejection, and slow cycling. Injection and extraction become somewhat more costly with the QUART, although the techniques are not essentially more difficult. Specific studies (in collaboration with Edward L. Hubbard and H. Paul Hernandez of the Design Study Group) of a 600-MeV design suitable for use with the AGS and CERN PS have been encouraging. Broader investigation of a QUART for the 200-BeV facility has suggested its possible competitiveness, but has indicated no clear advantage over the more conventional system presently proposed.

At the time of the preceding Semiannual Report, preliminary results had been obtained in a study of means for adjusting the closed orbit of an alternating-gradient synchrotron on the basis of data derived from pickup devices situated along the orbit, and a summary of these results had been prepared for inclusion in the Proceedings of the 1965 International Accelerator Conference at Frascati (Glen R. Lambertson and L. Jackson Laslett). Additional results were not obtained during the following months, due to the need to reprogram the computer programs employed in this and other phases of the Design Study in order to benefit from the increased capacity of new computing facilities that were becoming available at the Laboratory. Data are now again being obtained, the recent results being concerned with the response of a system for correction to imperfect information--either in the pickup signals themselves, or in the assumed characteristics of the accelerator, or in the corrections that it is believed have been put into effect. In addition, analysis and preliminary planning have been devoted to the evolution of alternative means of formulating the control problem, without introducing a prescribed grouping of controls that in fact might be significantly less than optimum.

The present study of equations that describe the beam envelope in the presence of space-charge forces and gradient errors (Frank S. Sacherer) represents a continuation of work reported by Lloyd Smith at the 1963 International Accelerator Conference in Dubna. This extension of the earlier work includes more exact consideration of antisymmetric focusing in the two transverse degrees of freedom, as would also be appropriate for an alternating-gradient synchrotron. This extension of the problem presents some distinctive mathematical questions in regard to the stability of the solutions that can be obtained, and the analytical work is being continued with some guidance from computational results for specific examples. (Lloyd Smith, Alper Garren, L. Jackson Laslett)

The program of investigation into coherent instabilities of particle beams was continued in collaboration with a number of workers. The fields of bunches of particles in resistive cavities--a basic ingredient in the theory--was completed and prepared for publication.⁴² The use of these fields in the

42. P. L. Morton, V. Kelvin Neil, and Andrew M. Sessler, Wake Fields of a Pulse Charge Moving in a Highly Conducting Pipe of Circular Cross Section (UCRL-16740, Feb. 1966) J. Appl. Phys. (to be published).

study of the instabilities of bunched beams was completed and put into a form suitable for publication.⁴³ The most interesting results of this work are prescriptions for designing accelerators so as to avoid the instabilities. Research into instabilities in colliding-beam machines is currently in progress, in collaboration with C. Pellegrini (Frascati), and P. Morton and M. Lee (SLAC). A review paper on this field was prepared⁴⁴ for publication in the Proceedings of the IVth International Conference on High Energy Accelerators, Frascati, 1965. (Andrew M. Sessler)

In analogy to the theory of Green's equivalent stratum, that can replace external sources for the production of a given electrostatic field within a closed surface, a prescription has been found for obtaining a surface-current distribution that will lead to a specified magnetic field within the region enclosed.

43. Ernest D. Courant and Andrew M. Sessler, Transverse Coherent Resistive Instabilities of Azimuthally Bunched Beams in Particle Accelerators, UCRL-16751, April 1966, to be submitted to Rev. Sci. Instr.

44. Andres M. Sessler, Instabilities of Relativistic Particle Beams, UCRL-16440, Oct. 1965.

The distribution includes a distribution of magnetic moment, normal to the surface, that can be interpreted as a double current layer, and the external field is shown to be zero. The existence of such a solution is of interest in connection with the objective of realizing certain magnetic-field configurations intended to reduce aberrations in β -ray spectrometers. A report of this analysis is given by L. Jackson Laslett, An Equivalent Distribution of Surface Currents for the Generation of a Prescribed Magnetic Field within the Enclosed Volume (UCRL-16587, Dec. 1965), and is scheduled for publication in J. Appl. Phys. (L. Jackson Laslett)

Previous research on a high-resolution high-luminosity β -ray spectrometer was concluded and prepared for publication.⁴⁵ Properties of the spectrometer are described--in some detail--in the last progress report. (Karl-Erik Bergkvist [Stockholm] and Andrew M. Sessler)

45. Karl-Erik Bergkvist and Andrew M. Sessler, A High-Resolution High-Luminosity Beta-Ray Spectrometer Design Employing Azimuthally Varying Magnetic Fields, UCRL-16802, April 1966, to be submitted to Nucl. Instr. Methods.

X. MISCELLANEOUS

Work is in progress concerning the hypothesis that the topology of space-time is not usual. An elementary length is embedded in space-time in such a way that probability is conserved and invariance under the full inhomogeneous Lorentz group is preserved. A pseudo-metrizable but non-Hausdorff topology is taken for the two-particle subspace; this induces the so-called λ topology, which is strictly finer than usual, on the space of an individual particle. (A pseudo-metrizable space is one whose open sets can be specified by a function $d(x, y)$ which satisfies the triangle

inequality, but for which $d(x, y) = 0$ for $x \neq y$.) The particle trajectories are supposed to be continuous in the λ topology, and to be U-continuous maps from a parameter space. An automatic nonlocality is thereby achieved, and the ultraviolet divergences of conventional field theory are in principle by-passed. Certain dynamical consequences of the structure of space-time are obtained, in particular a prediction of enhanced backward scattering at ultra-high energies. This work is being done in collaboration with M. B. Halpern. (David Atkinson, University of California, Physics Department)

MATHEMATICS AND COMPUTING SERVICES GROUP

Kent K. Curtis

During the period of this report (November, 1965, through April, 1966) members of the Mathematics and Computing Services Group performed the following tasks for the Laboratory research groups.

Data Acquisition

Spark Chambers

Lofgren Group

By use of previously written DDP-24 programs, preexperimental spark chamber film was scanned with SASS. The results have been used in the continuing study to improve the existing techniques for recognizing tracks and fiducials, and in the matching of tracks. A vector generator was installed in SASS and the necessary reprogramming was completed. These programs will be used for scanning film in the forthcoming Diboson experiment of Leroy Kerth. (Donald Zurlinden and Robert Belshe)

Several CDC 6600 programs have been written and added to the system which will do the analysis of the Diboson experiment. The program GUESS was written to serve as a rough momentum estimator. A program TRACK was written which will define the tracks of two particle trails from four chambers. The program BMAPS was written to prepare a set of magnetic field maps for use by the orbiting section of the program TRACK. (David Snyder)

Moyer Group

Programming has continued on the Vidicon Project. A PDP-5 program was completed which aids technicians and demonstrates possible techniques for controlling and checking the operation of the hardware. This program forms the framework for the final Vidicon PDP-5 System, and it will continue to grow as more features of the hardware are implemented. (Tony Schaeffer)

CDC 6600 programs have been written to read and process data tapes generated by the Vidicon PDP-5 System. One program was written to control the reading of data tapes, scale the data for the pattern recognition section, and plot the data. The pattern recognition section consists of a preliminary thinning program and a procedure for eliminating points which deviate from a least-squares line.

These programs have been completed to run successfully on simulated data. A second series of programs was written to perform statistical analysis to determine the instability and nonlinearity in the video system. These programs will grow as the need requires. (Tony Schaeffer and Les Wilson)

Crowe Group

Programming and analysis have continued on defining the tracks in the exit and target chambers for the Bevatron experiment. Several revisions have been made in the section that calculates the momentum of the incident particle. A program was written to allow exit film data to be substituted for the data generated by the track-recognition program. These programs are being rewritten to run on the CDC 6600. (Les Wilson and Edna Williams)

A 6600 program was written to process PDP-5 data tapes produced on-line in the cyclotron experiment. After some modification, the data from this tape are then put into a form which can be used by modified versions of the subroutines used in the Bevatron experiment. (Edna Williams)

Chemistry

Work continued on the PDP-7 Time-Sharing System for the Nuclear Chemistry Group. All the input and output routines are completed, a library tape system is operational, and several experimenters have analyzed their data on-line in a non-time-shared environment. (Myron Myers)

A set of PDP-7 programs has been written to plot data from a 400-channel or 1600-channel analyzer, to calculate and subtract background curves, and to do a statistical analysis of the results. These calculations are accomplished by use of the CRT and light pen. (Penny Collom)

A program was written for the 6600 which processes magnetic tapes from particle-particle correlation experiments. Up to six types of 512x512-channel co-incidence data are recorded on-line by a PDP-5 and written on magnetic tapes. The program edits the data and produces contour displays. (Edna Williams)

Health Physics

A program to generate and maintain a library of pulse-height analyzer runs was written to run on the DDP-24. (Bob Belshe)

General Physics Research

Powell-Birge Group

Two reports were made in reference to the proposed on-line Franckenstein Project. The first was a summary of proposed methods and resultant timings based on the concept of simultaneously controlling a number of measuring devices with a small digital computer.

The second report discussed the feasibility of allowing other users to collect data in real time on the 7044, concurrently with the Franckenstein data collection and reduction. (Don Zurlinden, Bob Belshe, and Myron Myers)

Small Computer Systems

DDP-24

The System Editor was revised to provide better error detection and to provide a map of all programs on the system tape. The new Assembler DAP2 was modified to fit LRL requirements, and was added to the system tape. (Robert Belshe)

PDP-7

The PDP-7 Assembler was converted to run on the CDC 6600. (Myron Myers and Penny Collom)

PDP-5

The PDP-5 Assembler was converted to run on the CDC 6600. A PDP-5 Library Tape System has been completed. It will load programs into memory from tape under keyboard control. In addition, it has all the necessary editing features. (Tony Schaeffer)

Biomedical Applications

Work on problems of biological interest concentrated mainly on the construction and testing of mathematical models, calculations related to the effects of radiation, and data processing or instrumentation projects. This work was sponsored by four organizations: Biodynamics, Biomedical Research, Health Physics, and Mathematics and Computing.

Quantitative Models

Refinement of previous work on the analysis of tracer iron kinetics in humans has led to a computer program IRK,¹ which was successfully used to determine the best-fitting parameters of a kinetic model. Parameter values so determined have been compatible with information obtained by other methods, for all 36 cases that have been processed. (Kenneth Wiley for Harry S. Winchell)

1. Physics Division Semiannual Report, UCRL-16411, Nov. 10, 1965, p. 31.

A paper by Grove C. Nooney, An Erythron-Dependent Model of Iron Kinetics (Grove Nooney, UCRL-16406, Sept. 1965), has been accepted for publication in the *Biophysical Journal*. Based on that paper, a program was written and used to simulate iron kinetics, thus providing comparisons of the consequences of various assumptions about iron acquisition and hemolysis. (Grove Nooney and Tom Mahan)

An analysis was undertaken of the distribution of various characteristics of cellular populations. Grove C. Nooney, Age Distributions in Dividing Populations (UCRL-16716,) shows the convergence to a limiting age distribution which is characteristic of the birth and death schedules of the population members. (Grove Nooney)

Chemical kinetics and steady-state tracer kinetics in biological systems can often be well approximated by systems of differential equations which represent the behavior of a given model involving unknown parameters. A general program DIFEQS² was previously written to find values of parameters in a system of ordinary differential equations which give the best fit of the solution to given data (taken from the actual biological system). Results of tests with this code show it to be superior to programs previously in use. (Eric Beals)

2. *Ibid.*, p. 32.

DIFEQS has been used to test several models of tracer kinetics of the photosynthetic carbon cycle. Although such tests led to the rejection of some simple models, insufficient data were available to reach a conclusive decision between various complex models. (Eric Beals for James A. Bassham, Biodynamics)

This program has also been used to fit compartmental models to kinetic tracer data on calcium and strontium metabolism in humans. (Tom Mahan for T. Sargent, Biomedical)

Radiation Effects

Program BRAGG was written to compute dosage versus distance curves for any ion in any homogenous medium. Agreement between calculated and experimental results has been excellent. (Gerry Litton for Cornelius Tobias and Roger Wallace, Biomedical)

Parts of the Livermore CRT contour-plotting package were adapted and the resulting program was used to plot radiation dosage contours computed via the program PITARY.¹

From a curve for ionization versus depth of penetration, the average radiation dose received at any point inside a spherical or cylindrical body rotating in the path of a columnar particle beam was computed by use of the program DERVISH. (Marjory Simmons for John Lyman, Biomedical)

A series of programs LYMER, LYMEV, and LYMPOL was written to obtain least-squares fits of various types of approximating functions to experimental data relating to radiation dosage measurements. (William Hogan and Kenneth Wiley for John Lyman, Biomedical)

The program ABSORB was written, which uses experimentally tabulated functions (density of foil vs. energy) to decrement the energy of a beam which is passed through a sequence of different foil barriers. The resultant value for the emergent energy is used to evaluate and compare functions given by theory. (William Hogan)

Least-squares fits of theoretical forms to data on the radiation sensitivity of the vestibular mechanism were carried out with the program ROTOR.¹ (Kenneth Wiley for Larry McDonald, Biomedical)

Several related Health Physics computer programs have been used in a sequential processing chain. These routines have now been merged into a single package to improve computing efficiency. (Eric Beals for Alan Smith, Health Physics)

Data Processing and Instrumentation

Several similar projects were carried out to automate collection and processing of data from various instruments. In most cases, the data had until recently been recorded on paper and further calculations had been carried out by hand or by separate computer programs. Paper tape or card punches have now been attached to these devices, and programs have been written which accept these data and consolidate further calculations into a sequence of format-compatible routines. These projects include automation of read-out from scintillation counters. (Ken Wiley for James A. Bassham, Biodynamics, and Frank Upham, Biomedical) and several programs for processing optical density data (Esther Coleman for James Thorne, Biodynamics, Gerry Litton for Edward Dratz, Biodynamics, and Tom Mahan for Gilles LaRoche, Biomedical)

Programs were written to process data obtained from regional blood flow studies. Measurements of radioactivity were fed from four counters to a PDP-8 computer. The data so generated were processed further by programs that applied calibration factors, corrected for cross-talk and displayed graphs of the final data. (William Hogan for Robert Hippensteele and Ernest Dobson, Biomedical). A program to correct and display data obtained from the Donner Laboratory scintillation camera was written. (Mark Horovitz for Malcolm Powell and Hal Anger)

A pilot study on computer processing of medical records was begun. Its objective is to establish criteria for the selection of diabetics to be subjected to radiation treatment. A set of categories, a coding scheme, and coding forms for the medical data were devised and are now in use. A scheme for computer processing of these data, and procedures for using them as an aid in making decisions concerning radiation treatment, have been formulated. (William Hogan for Henry Stauffer, Biomedical)

Other projects included statistical tests of the fit of one or two straight-line segments to sets of data (Erick Beals for Vivian Moses, Biodynamics) and a computation of the closed form for the dynamics of polymers calculated for a wide range of parameter values. In the latter problem, severe numerical difficul-

ties were encountered in evaluating the function, but these were overcome and satisfactory results were finally obtained. (Eric Beals for John Hearst, Biodynamics)

Accelerators and Magnets

The program SIBYL³ was converted for the CDC 6600 and is presently operational. Various tests to confirm the validity of the results have been performed. A time comparison between 7094 and CDC 6600 based on various cases run indicates a possible factor-of-2 improvement.

3. Joseph Dorst, Experience with Computer Models of Two-Dimensional Magnets, UCRL-11798, Mar. 1965; and J. S. Colonias, Operating Instructions for SIBYL Magnetostatic Program, LRL Internal Report AS/Theoretical/03, July 15, 1964.

A new program LYBIS was initiated. Its purpose was to obtain an algorithm for optimizing the pole face of a magnet. This program uses SIBYL as a subroutine, and is presently operational. (John Colonias, Ronald Holsinger, and Klaus Halbach)

A new program SAPPHO was initiated to optimize the pole face of a magnet with the effect of finite permeability taken into consideration. Even though the program had been operational, it found little application, because of problems arising in optimizing at high and low fields simultaneously. (John Colonias, Ronald Holsinger, and Klaus Halbach)

Program TRIMON (the CDC 6600 version of TRIM) has been completed and is presently operational. This program uses a finer mesh and the results show a noticeable increase in accuracy over the IBM 7094 version.

A study of the possibility of converging faster to a solution has given disappointing results. Neither Aitken's nor Newton's method has produced any improvement over the methods already in use. (Jim Spoerl for Charles Dols)

Our experience with magnetostatic computer programs in the last few years indicates that a new generation of computer codes is required to fill the gaps left by the existing codes. A series of long-term programs was initiated to fulfill these needs. The two-dimensional general-purpose magnetostatic program LIN, in rectangular coordinates, is suited for three-dimensional expansion. Effects of finite permeability are not included. This program, which was written by Dr. Richard Christian (of Purdue), is presently operational in a pre-

liminary form. Under study are the related programs RIN, which uses cylindrical coordinates, and TIN, which is three-dimensional. Also under study are a corresponding set of three programs, LINDA, RINDA, and TINDA, all of which include effects of finite permeability. (Jim Spoerl and Joseph Dorst for Charles Dols)

The conversion of synchrotron design orbit code SYNCH⁴ continued through this period with the debugging of various new storage and retrieval routines. A limited version of SYNCH for the CDC 6600 has been completed; however, not all the "pseudo-instructions" which are available in the 7094 version have yet been incorporated in the program. (Ardith Kenney for Alper Garren)

4. A. A. Garren and J. W. Eusebio, SYNCH--A Computer System for Synchrotron Design and Orbit Analysis, UCID-10153, April 10, 1965.

The radiation dosage code SHIELD⁵ was amplified to include H magnets, and converted to operate under the CDC 6600 computer system. (Thomas Clements for W. S. Gilbert)

5. W. S. Gilbert, Shutdown γ -Radiation Fields in an AGS Tunnel--Causes and Cures, UCID-10137, Dec. 1964.

Various codes were investigated with regard to use by the AGS Control Group for simulation of control systems given in block-diagram form. The program MIMIC⁶ was chosen and was adapted to the CDC 6600. This code contains plotting routines and various integration options. (Bobby Powell for John Colonias)

6. SCSA Internal Memo 65-12; Wright-Patterson Air Force Base, Ohio, R & D Division, Air Force Systems Command, May 1965.

The magnet alignment program ASTRAL⁷ was converted to the CDC 6600 and renamed PLANIT. It was revised to include averaging and Fourier analysis of equal responses. (Penny Collom for L. Jackson Laslett)

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

The program YORK was written. It calculates main-ring magnet response to sinusoidal excitation. (Penny Collom for Henry Lancaster)

The program VOCULT was initiated, which calculates the voltage and current response of a circuit to a step function. (Tom Clements for Henry Lancaster)

The curve-fitting program SPLINE was initiated. (Tom Clements for Joseph Dorst)

The program MERCURY, which solves the differential equations involved in the rotation of planet Mercury, was completed. (Penny Collom for L. Jackson Laslett)

The program EGLIM was rewritten for the CDC 6600. This program is used to find the resonant modes and the steady-state sinusoidal response of an equivalent network representing a magnet of the injector synchrotron. (Bobby Powell for Henry Lancaster)

Bubble Chamber Data Processing

During the past six months, programming has been done for the Trilling-Goldhaber, Powell-Birge, and Chinowsky physics groups. The general areas of work involved the maintenance of the production systems for data analysis, and the development and conversion of production programs for the CDC 6600.

Trilling-Goldhaber

The programs TGIF,⁸ TVGP,⁹ and SQUAW,¹⁰ originally developed by the Alvarez Group, were adapted to the needs of this Group and are now running on the IBM 7044. All event types for experiment 80 have been coded in TVGP and have been tested. The new ARROW system,¹¹ for loading fitted output from SQUAW into the existing EXAMIN¹² and PIOUS¹³ routines, was adapted and tested. Adaptations for Experiment 25 were begun.

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

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

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

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

12. For a detailed description of the EXAMIN System, see Alvarez Physics Note No. 274, Rev., Dec. 1, 1961.

13. For a detailed description, see Gerson Goldhaber, Trilling-Goldhaber Physics Note TG-42, June 9, 1963.

The first phase of the general plan for introducing the TVGP-SQUAW System into production use consists of validating its output for Experiment 80 by comparison with PACKAGE¹⁴ output, and this phase is 80% completed. (Robert Goldstein).

The summary and display program CHAOS¹⁵ was converted to the CDC 6600. Bookkeeping and other special subroutines were added. (Derik Armstrong)

The data analysis production system on the IBM 7094, which consists of the programs PANAL¹⁶ and PACKAGE, continued to be used as the primary production system. Extensive changes were made to handle Experiments 66 and 80. The major items include track switching (including the choice of various beam tracks), ionization calculations, chamber constants, event-type coding, and PACKAGE overlay in order to incorporate these additions within limits of available memory. This system of programs was used in the processing of data for ten distinct experiments. (Jim Miller, Jose Alvarez, and Bert Albrecht)

The SELECT¹⁷ and EXAMIN programs were extensively used on the IBM 7044 and 7094. Special subroutines were written and errors corrected. A new EXAMIN program was written on the 7094 for Experiment 66. (Emmett Burns and Derik Armstrong)

A bookkeeping system was initiated which provides an automatic method of following an experiment through the production system. (Derik Armstrong)

Powell-Birge

An event accounting program, BOOKIE, was written and is now in production on the IBM 7094. Conversion to the CDC 6600 was begun. This program logs the progress of events, experiment by experiment, from the measuring phase (FSD or conventional) through the FAIR¹⁸ system. This gives the

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

15. For a detailed description of CHAOS, see Derik Armstrong, June 8, 1964; also described in PDSR, UCRL-11132, Nov. 1963, p. 51.

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

17. PDSR (Physics Division Semiannual Report), UCRL-11776, Nov. 1964, p. 29.

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

physicists an automatic method of determining the status of events, detecting expediting errors and bottle-necks in the data analysis system, and avoiding the mysterious loss of events. Printed summaries and optional lists enable the physicist to have access to any desired set of events. (Bert Albrecht, Penny Collom, Noel Brown, and Myron Myers)

The FORTRAN IV program, SANE,¹⁹ which incorporates symbolic selection criteria and displays, went into production. Histogram lists and parameter lists were added. Conversion to the CDC 6600 was begun, and preliminary planning was done to incorporate the Vista consoles on the CDC 6600. (Noel Brown and Myron Myers)

19. PDSR, UCRL-16511, Nov. 1965, p. 25.

Chinowsky

The primary project was the modification of the TVGP and SQUAW Programs, written by the Alvarez Group, for a particular experiment. This modified system of programs is nearly completed for the CDC 6600. Three programs are used to produce input from TVGP by accepting data from various sources and rearranging the data format. One of these, for accepting HAZE tapes from the FSD, was written by Dave Johnson of the Alvarez Group. Two other programs were written, one to accept Franckenstein measurement data, and the other, to accept Roadmaker points (STB tapes) from the FSD scan table.

A group from SLAC is participating in the Chinowsky experiment. A program was written which uses the 7094 to convert from their format to ours. Aid was given the SLAC Group in getting an IBM 7044 version of TVGP and SQUAW running at Stanford. (Bill Gage)

General

HIST3D,²⁰ a generalized histogram program which plots a series of histograms in perspective, was converted from the IBM 7094 to the CDC 6600. Modifications were made to allow for more output flexibility. A program CURV3D was written to plot a series of curves in perspective. In particular, cross-section cuts of a function $z = F(x, y)$ may be drawn at specified values of y . (Noel Brown)

20. PDSR, UCRL-16099, May 1965, p. 27.

General Applications

A system of programs has been developed for studying the radiation spectrum generated at the time of spontaneous fission. The γ -ray, prompt conversion-electron, or prompt K x-ray events are recorded along with radiation-stabilizing and energy-calibration events on magnetic tape, event by event, as output from a multidimensional pulse-height analyzer. The objective of this radiation spectroscopy study is to resolve the spectra of radiation in coincidence with specific fission fragment pairs into discrete structures, thus defining the mass, charge, and multipolarity of the radiating nucleus. The program plots the energy-calibrated, normalized, and magnified radiation spectra with respect to mass interval. The locations and intensities of the spectrum peaks are resolved by a least-squares fit to a sum of Gaussians in program GAUSS. Results obtained by using these programs are to be included in a thesis.²¹

21. Rand Watson, A Study of the Internal-Conversion Electron Emitted Within 3 nsec After the Spontaneous Fission of Cf^{252} (Ph. D. thesis), UCRL-16798 (in preparation)

Programs were written to aid in the reported study of angular distributions of α -particle-induced fission fragments.²² A least-squares fit is made to center-of-mass angular distributions obtained from the fission of Bi^{209} and U^{238} by 23- to 115-MeV α particles. The theoretical functions, which define the differential cross section for fission at the center-of-mass angle relative to 90 degrees, are based on a model by Halpern and Strutinski,²³ and the nonlinear fitting parameter, K_0^2 , defines the variance of the internal quantized state of the nucleus at the saddle-point excitation energy for each bombarding energy. A theoretical K_0^2 , based on the Fermi gas model, is calculated for comparison. The results compared favorably at low energies, but the experimental value of K_0^2 became

22. S. Kapoor, H. Baba, and S. Thompson, Studies of Fragment Angular Distributions in the Fission of Bi^{209} and U^{238} Induced by Alpha Particles of Energies up to 115 MeV, UCRL-16706, Feb. 14, 1966.

23. D. Halpern and V. Strutinski, in Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1958, vol. 15, p. 408.

appreciably larger than the theoretical value at high excitation energies. This effect was widened with the inclusion of multichance fission in the Fermi model, and also with the consideration of the added effect of α -particle competition with the neutrons. (Claudette Rugge for Shyam Kapoor, H. Baba, and Stanley Thompson, Nuclear Chemistry)

A program ORTEP, which was originally developed at Oak Ridge and was adapted for use with LRL systems and equipment, draws two views of a crystal on the Cal Comp Plotter which produce a stereoscopic three-dimensional picture when seen through a viewer.

A program DELFT was written to evaluate integrals of discrete data which are given at unequal intervals of the independent variable. The integration procedure fits a cubic to four successive points by the method of divided differences, then integrates analytically, using the middle two points.

The program LSFIT was written which reads data consisting of corresponding values of t and r and makes a fit, using as independent variable one of the three forms t , $1/t$, or $\log t$, and using one of the three functional forms $\sum a_i r^{n_i}$, $\sum a_i (\log r)^{n_i}$, or $\sum a_i \exp(b_i r^{n_i})$ (where the n_i are fixed exponents).

The program TRANS was written to take the Fourier transform of an array of data. As an option, a decay exponential of the form $\sum_{i=1}^n a_i \exp(-b_i x)$ can be fitted to the input data and subtracted out before the transform is taken. This is useful if the input data constitute a periodic function superimposed on a decay exponential of much greater amplitude. Cal-Comp plots are made of the input and resulting transforms. The program AUTO, which computes the spectrum by taking the Fourier transform of the autocorrelation function, was modified to determine the phase of the peak frequency relative to an ideal curve of the peak frequency.

The program FRANK was written to use proton-proton elastic scattering data in an attempt to determine whether the scattering amplitude possessed appreciable spin dependence and a non-spin-dependent real part, as well as non-spin-dependent imaginary part. A few runs were made, but additional runs will be required in order to establish a conclusion. (Esther Coleman for Allen Zalkin, Eckart Matthias, and Victor Franco; Nuclear Chemistry; and for Richard Butterworth, Inorganic Materials)

Programs were written for the calculation of theoretical proton-deuteron and deuteron cross sections at high energies. The pro-

gram FRANCO2 calculates either the differential elastic and total elastic cross section or the differential elastic-inelastic and total elastic cross section for proton-deuteron scattering. The calculations include the Coulomb effect, and both single and double interactions are treated.

The second program FRANCO3 makes similar calculations for deuteron-deuteron cross sections. The calculation involves the nucleon-nucleon elastic scattering amplitudes and the ground-state wave function. Single, double, triple, and quadruple interactions are treated.

FRANCO4 is a program which calculates two models for the excitation of a hydrogen atom from its ground state to its 2S state. The first model uses the Born approximation, and the second uses a simple high-energy approximation and treats the effects of double interactions.

The program UOFGAM was written to calculate the Coulomb phase shift in a high-energy approximation as a function of the ratio of the impact parameter to the range of the charge distribution for a Gaussian charge distribution. (Deanna Wilber for Victor Franco, Nuclear Chemistry)

Work was completed on calculations to evaluate the effective atmospheric densities for geomagnetically trapped 125-MeV protons whose guiding centers mirror between 200 and 560 km altitude in the South Atlantic anomaly. The effective atmospheric densities and scale heights experienced by the particle and its guiding center were calculated. Rates of energy loss by ionization were also calculated, with atmospheric composition and the ionization energies for each constituent taken into account. The model atmospheres used in the calculations are those of Harris and Priester²⁴ and of Johnson.²⁵ The earth's magnetic field was approximated by a 48-term spherical harmonic expansion due to Jensen and Cain.²⁶ The ATMOS²⁷ program was used to perform

24. J. Harris and W. Priester, Theoretical Models for the Solar Cycle Variations of the Upper Atmosphere, Goddard Space Flight Center, N. A. S. A., Rept. X-640-32-70, 1962.

25. T. S. Johnson, Structure of the Upper Atmosphere, in Satellite Environment Handbook, Second Edition, edited by T. S. Johnson (Stanford University Press, Stanford, California, 1965), pp. 3-20.

26. D. C. Jensen and J. C. Cain, An Interim Magnetic Field (abstract), *J. Geophys. Res.* **67**, 3568 (1962).

27. PDSR, UCRL-11776, Nov. 1964, p. 26.

the calculations. The results of this work have been reported, Harry Heckman and Victor Brady, Effective Atmospheric Losses for 125-MeV Protons in the South Atlantic Anomaly, (UCRL-16592, Dec. 1965) and are to be published in J. Geophys. Res. The program was also used to study some of the invariant properties of trapped particle motion. A dipole approximation to the earth's magnetic field was used in the calculations, and the numerical results were compared with the theory. (Victor Brady for Harry Heckman, Nuclear Emulsion)

Work was continued on a study of the beam of the 184-inch cyclotron in the region of the ion source. The calculations were done with a modified version of a computer program called PINWHEEL, which was written at Michigan State University.²⁸ The program was converted to the 6600 and was modified to include frequency modulation and a narrow-gap approximation to the electric field. The modified program, called CYCRST, was used to compute the capture efficiency of the cyclotron for several electric and magnetic fields. The results were compared with the theoretical work of Bohm and Foldy.²⁹ (Victor Brady for David Clark, 88-Inch Cyclotron Group; and for David Judd, Theoretical Physics)

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

29. D. Bohm and L. Foldy, Theory of the Synchro-Cyclotron, Phys. Rev. 72, 8 (1947).

Work was started on an inventory control program STAP6, which maintains the laboratory inventory for each site. Some of the transactions that can be processed are receipts, on-order items, intersite transfers, issues, returns, value adjustments, inventory adjustments, and deletions from stock. Various reports, which include number of each type of transaction, reorder messages, error messages, exception messages, and current status summary, are generated by the program. (Deanna Wilber for Thomas Hitchcock and Richard Lieser, Stores)

Work was continued on the program PUZZLE,³⁰ which was developed for the automatic design of printed circuit boards. The program designs circuit boards containing any combination of 8-pin micrologic, 10-pin micrologic, and discrete components. The output consists of drawings of the circuitry on each side of the board and a drawing of holes to be drilled. The drawings are produced by the Cal Comp Plotter, using a special wide

30. PDSR, UCRL-16514, Nov. 1965, p. 30.

pen and plastic plotting paper, and are introduced directly into the printed circuit procedure, thus eliminating drafting time and effort, as well as automating the design process. (Deanna Wilber for Ronald Zane, EE Research and Development)

A program EXINT was written to evaluate a potential energy $V(r)$ by integrating analytically a function

$$p(r) = \sum_j [\sum_k A_{jk} r^{m_k} \exp(-C_{jk} r)]^2.$$

The A_{jk} , m_k , and C_{jk} are output from program SCF3, which uses a self-consistent field method for determining wave functions for closed-shell ions. Plots of $V(r)$, and of a function representing the effective potential energy of an impinging electron, were made. (Tom Clements for Herschel Rabitz, Nuclear Chemistry)

Subroutines which compute Clebsch-Gordan and Racah coefficients (according to the formulae found in Rotenberg et al., The 3-j and 6-j Coefficients) were rewritten for the CDC 6600.

A contour plotting subroutine CONMAP was written which searches for and plots specified level curves of a function of two variables which is given as a two-dimensional array. (Marjory Simmons for Math and Computing)

The nonlinear minimization programs previously described³¹ were converted and certified to run correctly on the CDC 6600. (Eric Beals for Math and Computing)

31. PDSR, UCRL-16514, Nov. 1965, p. 34.

A routine CENTER, which centers a set of BCD characters in a field of arbitrary length, and a routine FIXLBL, which generates fixed point labels for use with the Cal Comp package, were completed. (Gerry Litton for Math and Computing)

Mathematics and Computing Research

Work was completed on a report, Paul Concus, Numerical Solution of the Nonlinear Magnetostatic-Field Equation in Two Dimensions, UCRL-16287, Rev., Dec. 1965. The report extends the iterative method formulated previously (in Paul Concus, On the Calculation of Nonlinear Magnetostatic Fields, UCRL-16287, July 1965) to include an irregular rectangular mesh and arbitrary electric current distributions. This method has been

applied to numerically solving Plateau's problem in restricted form. Extensive tests were made on a sample problem, and the method performed successfully. A report by Paul Concus, Numerical Solution of Plateau's Problem, is in preparation.

The method is also being applied to numerically solve the differential equation governing the equilibrium of fluids subject to surface and gravitational forces. A program is being written to determine the equilibrium configuration of fluids in capillary tubes of square cross section.

A study was made of a conformal transformation involving the integral of the complex Gudermannian for the Accelerator Study Group, to be used in designing magnetic pole faces. A numerical method for calculating the transformation was developed.

A study was made of a renewal counting process arising in a nuclear counting experiment, for the Physics Instrumentation Systems Group. A solution was found for the expected value of the percentage of total events that would pass undetected. (Paul Concus)

Samuel J. Penny presented a paper³² on Decision Lattices at the Spring Joint Computer Conference in Boston in April.

32. Samuel J. Penny and James H. Burkhard, Multidimensional Correlation Lattices as an Aid to Three-Dimensional Pattern Reconstruction, UCRL-16478, Jan. 26, 1966, presented at the Spring Joint Computer Conference, April 26-28, 1966, Boston, Mass.

Systems Programming

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

1. Software for the CDC 6600 computer was put into operation at the time of installation of this computer at the Laboratory. It was necessary to make several modifications to the prerelease version of the Chippewa Operating System (COS) in order to run Laboratory problems. These modifications included improved tape-handling routines (Joyce Johnston, Bob Tracy, and Bill Roten--all CDC), improvements to the console display package (Bob Tracy), improvements to the FORTRAN compiler (Dave Stevens), improvements to the systems dump routine (Chuck Stevenson), a self-loading program to dump peripheral processors (Doug Brainard), implementation of a SAVE and RELOAD package from NYU (Bob Tracy), a driver to handle more than one printer (Bob Tracy), implementation of

the NYU recovery monitor (Bill Roten), improved communication between Operator and Programming via control cards (Bob Tracy), a preliminary version of a program which converts 7094 binary tapes to 6600 format (Jane McDonald) with later improvements (Myron Myers, Chuck Stevenson), and programs to perform Cal Comp plotting from a 6600 program. (Bill Benson)

2. Because of CDC's inability to deliver software for the 6411 input-output module, the entire system is being designed and written at LRL. This has involved a considerable investment in systems programming manpower, with four full-time people (Walter Hutchinson, Samuel Penny, Douglas Brainard, and Jerry Borges) and one part-time programmer (Jane McDonald). A "Scratch" system is presently running which permits the 7094 card-to-tape and tape-to-printer support functions to be run on the 6411 under control of a teletype console, with two or more such support functions being permitted simultaneously.

Plans have been made for implementation of the entire 6411 system in stages, with a target date of Jan. 1, 1967, for the completion of the final phase. Drivers were written for the CDC 210 consoles, teletypes, and Cal Comp Plotters, but none of these has been checked.

A considerable amount of internal documentation was produced for the use of those writing the system, but no papers have yet been written for external distribution.

3. A number of other projects were undertaken. Initial steps were taken to run with the standard distributed Chippewa systems tape version 1.0. A Chippewa Users' Manual was produced (Dave Stevens). An accounting routine was written to automatically produce tapes which are used as the basis for 6600 recharges (Robert Belshe and Fran Permar). A SORT routine was written for the 6600 and distributed (Dave Stevens).

SPY a routine for monitoring the P counter during the running of a program, was written and distributed. This routine can be used to locate the areas in which a program is spending its time, so that the programmer can investigate those areas for possible code improvements. (Dave Stevens)

UPDATE, a routine to allow updating of source programs which are kept on tape, was written and placed on the system tape. (Dave Stevens)

A study was undertaken on improvements to the scheduling procedure within the Chippewa system. A program, PRIOR, was written which adjusts priorities on the basis

of CP and PP time used. About 10% improvement was noted. This study is continuing. (Dave Stevens)

Some simulation of the 6800 was conducted to study various schemes for segmenting programs using mass core storage and either hardware or software paging. (Sam Penny)

Programs were written to utilize the CDC 250 display as an input-output device to FORTRAN programs. They are being checked with the 250 system attached to the 6411, and the hardware will be recabled to the 6600 when the software is operational. (Bill Benson)

Computer Operations

Site preparation in Building 50A for the CDC 6600 computer was completed in November 1965.

The IBM 7044 computer was moved to Building 70A, Room 2265, in November 1965.

In December 1965 a minimum CDC 6600 computer was delivered and installed at the

Laboratory. This configuration consists of a 6600 main frame, a 6602 console, ten 607 magnetic tape drives, a 6603 disk file and controllers, two 501 printers and controllers, a 405 card reader and controller, and a 415 card punch and controller. A thirty-day acceptance test of this equipment was begun on January 11, 1966, and completed on February 10, 1966.

In April 1966 the IBM 7094-B computer and an IBM 1460 computer were returned to IBM.

The minimum CDC computer was shut off and relocated to make room for the remainder of the CDC 6600 computing system, which includes a 6411 input-output module; two 6603 disk files and controllers, two 607 magnetic tape drives, a 501 printer and controller, a 250 display system controller with five display consoles and a display camera, a DD-10 controller with five remote consoles, three remote type-writers, a 6603 console, and a 3691 paper tape reader and punch. This equipment was installed in April 1966, and is currently undergoing acceptance tests. (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

Differential cross sections for p-p scattering were measured for incident momenta 3, 5, and 7 BeV/c, and momentum transfer in the region $-t = 0.01$ to $-t = 5$ (BeV/c)². The scattered protons were momentum-analyzed with magnetic spectrometers and detected with scintillation counters for the missing-mass spectrum $p + p \rightarrow + x$ for $x = \text{proton}$. The Bevatron external proton beam was used with a hydrogen gas target for recoil momenta from 75 to 600 MeV/c and a polyethylene target, with matched carbon target for subtraction, for recoil momenta 500 to 4000 MeV/c. Statistical errors were approximately 2% at low momentum transfer, and increased to about 5% for 90-deg scattering in the center of mass. The data indicate shrinkage of the diffraction peak with increasing incident energy and a strong energy dependence of $d\sigma/dt$ at 90 deg, and are consistent with a logarithmic decrease in the total elastic cross section with increasing center-of-mass energy. Measurements at momentum transfers in the Coulomb interference region give ratios of the real to imaginary parts of the forward scattering amplitudes equal to -0.43 to 3 BeV/c, -0.39 at 5 BeV/c, and -0.34 at 7 BeV/c. These data also indicate a similar angular dependence for both real and imaginary parts of the nucleon-nucleon scattering amplitude.

* Present address: Edgerton, Germeshausen and Greer, Las Vegas, Nevada.

† Present address: Pan American World Airways, Guided Missile Range Division, Patrick Air Force Base, Florida.

MEASUREMENT OF THE BRANCHING RATIO
 $K^+ \rightarrow e^+ \nu$ $K^+ \rightarrow \mu^+ \nu$ Alan R. Clark, Bruce Cork, Tom Elioff,
Denis Keefe, David Newton, and W. A. Wenzel

An experiment for an accurate measurement of this branching ratio has been approved by the Bevatron scheduling committee, and detailed design studies are in progress. The

K^+ will be brought to rest near the center of a magnet with pole-piece diameter 65 inches similar to M5. By shaping these pole pieces the magnetic field can be made to focus all particles of a unique momentum which start from a point source near the magnet center back to an image point, which is also near the magnet center. It is intended to surround the point source with a high-pressure gas Cerenkov counter to help in the rejection of muons from K^+ decay, and to surround the image point with a spark chamber containing lead to help further in rejection of muons as well as preventing multiple orbits of the charged particles. Present design studies indicate that the acceptance solid angle should be about 0.4 of 4π , which will give about 2 Ke_2 events per hour. The triggering rate on all other decay modes, mainly Ke_3 , can be cut down to less than one per Bevatron pulse, and all of these can be rejected, on the scanning table, from the very good momentum measurement to be expected from this apparatus. The experiment is scheduled to begin in December 1966.

PION-PION INTERACTIONS
FROM $\pi^- + p$ COLLISIONS AT 3 AND 4 BeV/cCarl M. Noble, Denis Keefe, Leroy T. Kerth,
John J. Thresher,† and W. A. Wenzel

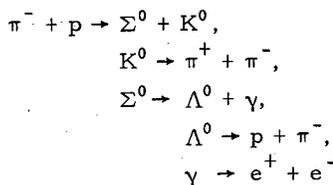
The final-state $\pi-\pi$ interactions in the process $\pi^- + p \rightarrow \pi^+ + \pi^- + n$ have been studied at incident momenta of 3 and 4 BeV/c by means of a magnetic spectrometer and spark chambers. A lead "sandwich" counter system surrounding part of the liquid hydrogen target rejected highly inelastic events to enhance detection of the $\pi^+ \pi^- n$ final state. The system, biased for low Δ^2 acceptance, recorded 879 and 1248 events with $\Delta^2 < 9 \text{ m}\pi^2$ at 3 and 4 BeV/c respectively. The energy of the peak in the dipion mass spectrum at the ρ mass depends on the dipion scattering angle and the Treiman-Yang angle. One Ph. D. thesis and one contributed paper at the 1966 Washington APS meeting have been completed (see items 7 and 8 in "Papers and Publications").

† Present address: Rutherford High-Energy Laboratory, Chilton, Berkshire, England.

POLARIZATION OF Σ^0 IN
 $\pi^- + p$ INTERACTIONS

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

Three hundred examples of $\Sigma^0 + K^0$ production have been detected by spark chambers from $\pi^- + p$ interactions in the pion momentum range 1200 to 1400 MeV/c. Events were detected in a spark chamber of semicylindrical shape by the charged secondaries of the reaction sequence



after lead plates.

The differential cross sections showed no significant variation with pion momentum in this range. A statistically significant polarization was found to exist at 1.325 BeV/c in the backward hemisphere of Σ^0 production.

A paper by Crollius, Cook, Cork, Keefe, Kerth, Layson, and Wenzel, Polarization of Σ^0 Hyperons, UCRL-16089 Rev., April 1966, is to be submitted to Phys. Rev.

*Present address: University of Washington, Physics Department, Seattle, Washington.

†Present address: Aerospace Corporation, San Bernardino, California.

K^- - PROTON INTERACTIONS
FROM 700 TO 1400 MeV/c

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 $K^- - p$ scattering have been measured at 16 momenta in the range 700 to 1400 MeV/c. A total of 17 000 elastic events were observed

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

‡‡Present address: Rutherford High Energy Laboratory, Chilton, Berkshire, England.

§Present address: Rutherford High Energy Laboratory, Chilton, Berkshire, England.

**Present address: Brookhaven National Laboratory, Upton, Long Island, New York.

with narrow-gap cylindrical and parallel-plate spark chambers.

A Legendre polynomial fit to the differential cross sections required fifth-order terms, but not sixth-order, in the region of the 1765- and 1815-MeV resonances. The behavior of the coefficients suggested a highly elastic resonance at 1815 MeV and a rather inelastic resonance near 1765 MeV.

The polarization of recoil protons was measured at five of these momenta, and phase-shift analyses were made on the basis of $K^- - p$ elastic differential cross sections from this and other experiments as well as all available data on the total cross section, charge-exchange cross section, and the $K^- - n$ total cross section between 110 and 1400 MeV/c. These phase-shift analyses supported either of the assignments $F_{5/2}$ or $D_{5/2}$ for the 1815-MeV resonance. A possible, but not unique, set of energy-dependent phase shifts was obtained by assuming a $D_{5/2}$, $T = 1$ resonance at 1765 MeV, and an $F_{5/2}$, $T = 0$ resonance at 1815 MeV.

p-p AND p-d INTERACTIONS
AT 3-TO-7 GeV/c

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

Analysis is continuing on the reactions

- (1) $p + p \rightarrow p + p$,
- (2) $p + p \rightarrow p + N^*$,
- (3) $p + p \rightarrow \pi + d$,
- (4) $p + p \rightarrow K + \Lambda + p$,
- (5) $p + p \rightarrow \pi + x$,
- (6) $p + d \rightarrow p + d$, and
- (7) $p + n(p) \rightarrow p + n(p)$.

The apparatus has been described in a report given at the Purdue Instrumentation Conference [Charles M. Ankenbrandt, IEEE Transactions NS-12 (4), 113 (1965)]. The analysis of Reactions (1) and (2) is essentially complete, and an invited paper at the Washington APS meeting was given by Charles M. Ankenbrandt [Bull. Am. Phys. Soc. 11, 380 (1966)].

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

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

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

$$\pi^\pm + p \rightarrow \pi^\pm + \pi^+ + n,$$

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

$$\pi^\pm + p \rightarrow \pi^+ + \pi^0 + p,$$

and

$$\pi^\pm + p \rightarrow K^\pm + K^0 + p,$$

with incident pion momenta between 2 and 5 BeV/c. Several regions of particular interest are the K^+K^- spectrum in the vicinity of the f^0 (1250 MeV), the $\pi^+\pi^-$ spectrum in the ρ region (700 to 800 MeV), and the $\pi^+\pi^-$ spectrum around 1650 MeV, where structure has been reported recently.¹ Results from a previous experiment by this group² showed experiment should increase the statistics in this region considerably, and also provide better measurement precision. The apparatus is now being assembled at the Bevatron. Data taking is scheduled to begin near the end of May 1966.

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

Σ^\pm DECAYS

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

The Bevatron scheduling committee has accepted a spark chamber experiment to study the decay of the Σ^\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

- (a). Measurement of the decay parameters α , β , and γ , for $\Sigma^+ \rightarrow n^\pm + n$.
- (b). Remeasurement of α for $\Sigma^+ \rightarrow \pi^0 + p$,

and accurate determination of β and γ for this mode.

(c). Remeasurement of α 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.

The experiment is scheduled to start at the Bevatron in July 1967.

PAPERS AND PUBLICATIONS

1. Ching Lin Wang, Recoil-Proton Polarization in Negative Kaon-Proton Elastic Scattering Between 700 and 1400 MeV/c Incident Kaon Momenta (Ph. D. thesis), UCRL-11881, April 19, 1965.
2. William R. Holley, K^- -Proton Elastic Scattering in the Momentum Range 700 to 1400 MeV/c (Ph. D. thesis), UCRL-16274, October 22, 1965.
3. A. R. Clyde, Bruce Cork, D. Keefe, L. T. Kerth, W. M. Layson, and W. A. Wenzel, Proton-Proton Elastic Scattering, Bull. Am. Phys. Soc. 10, 1197 (1965).
4. R. L. Cfolius, V. Cook, Bruce Cork, D. Keefe, L. T. Kerth, W. M. Layson, and W. A. Wenzel, Associated Production of Σ^0 's Near 1.3 GeV/c, Bull. Am. Phys. Soc. 10, 1196 (1965).
5. W. A. Wenzel, Recent Developments in Spark Chambers (UCRL-16542, February 28, 1966); presented at Tenth Scintillation and Semiconductor Counter Symposium, March 2-4, 1966, Washington, D. C.
6. Richard L. Lander, Werner A. W. Mehlhop, H. J. Lubatti, and Gerald L. Schnurmacher, Solid-State Devices as Detectors of Coherent High-Energy Interactions, Nucl. Instr. Methods 36, 269 (1965).
7. Carl M. Noble, Jr., Pion-Pion Interactions from π^-p Collisions at 3 and 4 BeV/c (Ph. D. thesis), UCRL-16655, Feb. 1966.
8. C. M. Noble, D. Keefe, L. T. Kerth, J. J. Thresher, and W. A. Wenzel, Pion-Pion Interactions from π^-p Collisions at 3 and 4 BeV/c, Bull. Am. Phys. Soc. 11, 325 (1966).
9. Charles M. Ankenbrandt, Isobar Production in Proton-Proton Collisions from 3 to 7 GeV/c, Invited Paper for Meeting of American Physical Society, April 25-26, 1966, Washington, D. C.

PHYSICS RESEARCH

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

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

Thomas B. Risser

This experiment is designed to measure the recoil neutron polarization in the region of the proposed P_{11} and S_{11} resonances near 600 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 to do the $K_2^0 \rightarrow 2\pi^0$ experiment, further construction has been temporarily slowed down. The only major item not nearly finished is the large cylindrical spark chamber. It is currently being assembled.

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 continues; 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 400 000 pictures have been measured to date.

SPARK CHAMBER PULSER

Sherwood I. Parker and Charles A. Rey

This experiment has now been written up and submitted to Nuclear Instruments and Methods.

POLARIZATION IN p- α SCATTERING
BETWEEN 27 AND 63 MeV

E. Boschitz, M. Chabre, H. E. Conzett, E. Shield, R. J. Slobodrian, and W. Tivol

Polarizations in p-He⁴ elastic scattering were measured at proton energies of 26.8, 34.2, 44.1, 54.8, and 63.3 MeV, in which the polarized proton beam facility at the 88-inch cyclotron was used. The beam polarization, P_1 , has been determined in previous experiments, and the polarization of the elastic p-He⁴ 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 10 to 63 MeV. A phase-shift analysis has been performed, and a paper is being prepared for publication.

DETERMINATION OF THE
NEUTRON-NEUTRON SCATTERING LENGTHE. Baumgartner, H. E. Conzett,
E. Shield, and R. J. Slobodrian

We have determined the neutron-neutron scattering length from a final-state interaction in the reaction $H^3(d, He^3)2n$. This experiment was performed with 32.7- and 40.4-MeV deuteron beams of the 88-inch cyclotron. Cross sections ($d^2\sigma/d\Omega dE$) for He³ were obtained with high statistical accuracy (18 000 events at $\theta_{lab} = 6$ deg) and an energy resolution of 240 keV. In addition, cross sections for H³ from the mirror reaction $He^3(d, H^3)2p$ were measured at 30 MeV. The nucleon-nucleon final-state interaction appears as a strongly peaked distortion of phase space at the high-energy end of the spectra.

The scattering lengths obtained from best fits to the data are shown in Table I.

Table I. Scattering lengths obtained from best fits to data.

Scattering length (F)	Nucleon-nucleon energy (MeV)	Number of Events
$a_{nn} = -16.1 \pm 1.0$	0 - 1.57	17 782
$a_{pp} = -7.69^{+0.61}_{-0.67}$	0 - 1.58	11 268
$a_{pp} = -7.41^{+0.39}_{-0.49}$	0 - 2.38	21 798

The determination of a_{pp} agrees within experimental errors with the determination from low-energy proton-proton scattering.

In addition, variation of the n-n effective range, r_e , in fits to the data gave a best fit for $r_e = 3.2 \pm 1.6 F$. Thus it is possible that further experiments of even greater accuracy could test the limit of validity of final-state interaction theory and determine the neutron-neutron effective range.

DOUBLE-CHARGE-EXCHANGE EXPERIMENT

V. Perez-Mendez, Leon Kaufman,
and Princeton Group

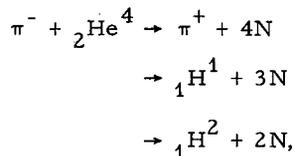
The final data analysis¹ of this experiment confirms our early results that the cross section for producing $\Delta T_Z = 2$ analog states by double-charge-exchange reactions on vanadium and zirconium is considerably smaller than predicted by the theory of Barshay and Brown,² i. e., less than μb (expt) as compared with $\approx 20 \mu b$ (theory). The broad energy distribution of double-charge-exchange events is interpreted in terms of noncollective excitation models.

1. Boynton, Solomon, Devlin, and V. Perez-Mendez, *Bull. Am. Phys. Soc.* **11**, 37 (1966).
2. Barshay and Brown, *Phys. Letters* **16**, 165 (1965).

π^- - HELIUM INTERACTIONS

Leon Kaufman, A. Greenberg,
and V. Perez-Mendez

An experiment is being prepared for measuring the cross section for π^- interactions leading to multineutron final states. The experimental arrangement is similar to that used in the above experiment, with two additional wire spark chambers and associated magnetostrictive readout. We propose to look at the reactions



and to study the final-state interactions of the neutrons by the measured deviations from phase space of the charged particle in each case.

In addition to these reactions we will search for $T = 2$ states in helium produced

by inelastic π^- scattering.

HELIUM-FILLED WIDE-GAP CHAMBER PROJECT

Albert W. Stetz and Victor Perez-Mendez

A wide-gap streamer chamber filled with helium is now set up outside the proton cave in the 184-inch cyclotron. The quality of the tracks from low-energy protons (50 to 100 MeV) and from He recoils is being studied. An image intensifier tube has been set up to look at the tracks in early stages of the streamer development in time. We expect to use a polarized proton beam on the same set-up to study the analyzing power of helium in p-He collisions above 50 MeV.

MAGNETOSTRICTIVE READOUT DEVELOPMENT FOR SPARK CHAMBERS

V. Perez-Mendez, L. Kaufman,
and J. Pfab

We have tried a number of methods by which the magnetostrictive delay line readout scheme can be used in magnetic fields. The use of iron-cobalt alloy wires oriented approximately perpendicular to the magnetic field permits operation up to 20 kG with suitably shielded magnetic "receive" transducers or with piezoelectric transducers. A different method involving the generation of acoustic pulses in nonferromagnetic wires, which we have tested, is suitable for operation in all magnetic field orientations and magnitudes.¹

The overall accuracy of particle track measurement has been determined from the wire chambers used in the double-charge-exchange experiment² and from a beam-finder spark chamber that we have used elsewhere.³ From these we find that the accuracy of track position measurement within is ≈ 0.3 mm for particles traversing wire chambers with 1-mm wire spacing when the measurer is crossing the chambers perpendicularly.

1. Magnetostrictive and Piezoelectric Readout of Spark Chambers in Magnetic Fields, L. Kaufman, V. Perez-Mendez, and J. Pfab, UCRL-16536, 1966.

2. Design and Performance of Wire Spark Chambers and Magnetostrictive Delay Line Readout System, V. Perez-Mendez, T. Devlin, J. Solomon, and T. Droege, Princeton-Penn Accelerator Report, PPAP 588-E, 1966.

3. Beam Profile Spark Chamber with Magnetostrictive Readout, H. Weisberg and V. Perez-Mendez, UCRL-16704, Feb. 1966.

CHECK ON CPT INVARIANCE FROM
 π^+ AND π^- LIFETIMES

David S. Ayres, David O. Caldwell,
 Arthur J. Greenberg, Robert W. Kenney,
 and Richard J. Kurz

The primary experimental effort for the last six months has been to eliminate systematic fluctuations at least to a level compatible with the potential statistical precision.

The pion beam has been improved in the following ways: (a) a vacuum system has been installed, (b) anticoincidence scintillators have been added to eliminate muons resulting from pions that decay between the final momentum determination and the last defining counter, and (c) a gas Cerenkov counter has been installed to veto electrons in the beam.

The vacuum system of the liquid hydrogen velocity-selecting Cerenkov counter has been improved to eliminate a long-term deterioration in the counter efficiency caused by condensation on the optical window of the liquid hydrogen radiator.

The present levels of precision are: within $\approx 1\%$ for the ratio of lifetimes, $\approx 0.5\%$ for the absolute π^+ lifetime, $\approx 1\%$ for the absolute π^+ lifetime.

The current measurements of these quantities are compatible with equality of the π^+ and π^- lifetimes.

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

D. Cheng, R. Eandi, A. C. Helmholz,
 R. W. Kenney, W. Oliver, S. Parker,
 V. Perez-Mendez, C. Rey, D. Caldwell,*
 R. Cence,† B. Jones,† V. Peterson,†
 and V. Stenger†

Work is continuing on the measurement of the branching ratio for $K_L^0 \rightarrow \pi^0 + \pi^0$. Knowledge of its value is important for a full understanding of the CP-nonconserving process responsible for the observed decay

$K_L^0 \rightarrow \pi^+ + \pi^-$. The experiment uses nearly monoenergetic K^0 's produced by a beam of 0.97 ± 0.04 -BeV/c π^- mesons incident on a 1.2-mm H_2 target. A magnetic field sweeps out charged particles, and a lead filter interleaved with scintillators removes most of the γ 's from the beam and prevents the remaining ones from triggering the spark chambers. The K^0 's pass through a collimator, through a four-sided tunnel made of scintillator-lead-lucite anti-counters and then into a decay volume surrounded on five of its six sides by anticounters, an Al plate spark chamber module, and Al-Pb plate spark chamber modules with a thickness of seven radiation lengths. Only 3% of the main background process $K_2^0 \rightarrow 3\pi^0$ should 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 and construction have been completed. An intensity of about $7 \times 10^6 \pi^- / 10^{12}$ protons is expected at the H_2 target.
- (b) More detailed Monte Carlo calculations have been run to estimate true and background-event rates. Their results agree with the earlier estimates used in the proposal.
- (c) The necessary spark chambers, mirrors, supporting frames, Cerenkov counters, and scintillators have been built. The counters and large spark chambers have been successfully tested.
- (d) The trigger rate for the spark chambers has been measured, and it is not excessive.
- (e) Assembly is continuing on the pulsers and gas system parts needed for the simultaneous operation of all the chambers. Obtaining the necessary number of pulser capacitors has taken longer than expected, but so far has not held up the experiment.
- (f) The chambers and mirrors are now being put into place.

* University of California Santa Barbara
 † University of Hawaii, Honolulu, Hawaii

PHYSICS RESEARCH

Wilson M. Powell and Robert W. Birge in charge

π^+ p INTERACTIONS IN THE
MOMENTUM INTERVAL 2.9 TO 4.2 BeV/c

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

We have taken 150 000 pictures of π^+ p interactions in the 72-inch bubble chamber, divided among the π^+ momenta 2.9, 3.2, 3.5, 3.7, 3.9 and 4.2 BeV/c. The major purpose of the experiment is a detailed analysis of the $T = 3/2$ nuclear resonance, $^1 N^*(2830)$, with particular emphasis on the decay modes $N^{*++} \rho^0$, $N^{*++} \omega^0$, and $N^{*++} \omega^0$. The available data in the literature indicate that the $N^{*++} \rho^0$ channel may be particularly strong. To date we have measured approximately 16 000 four-prong events by means of the FSD device. This represents one kind of the available data. We are simultaneously measuring the backward π^+ p elastic-scattering angular distributions at these energies to aid in determining the quantum numbers of this resonance.

1. A. Citron et al., Phys. Rev. Letters 13, 205 (1964).

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

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

The total cross section, angular distribution, and Λ polarization have been measured over the c. m. energy interval 1660 to 1900 MeV. The data have been analyzed to elucidate the partial-wave amplitudes in this channel. The study confirms the spin parity assignment $J^P = 5/2^-$ for $Y_1^*(1765)$ and determines the parity of $Y_1^*(2030)$. These results were presented at the April 1966 Meeting of the American Physical Society. [Wesley M. Smart, Robert P. Ely, George E. Kalmus, and Anne Kernan. The Reaction $K^- n \rightarrow \Lambda \pi^-$ in the Center-of-Mass Energy Interval 1690 to 1870 MeV, Bull. Am. Phys. Soc. 11, 342 (1966).]

$K^- d$ AND $K^- n$ ELASTIC SCATTERING

George E. Kalmus and Nathan Jew

Preliminary data, based on about one-third of the film, were presented at the Washington American Physical Society Meeting in April. [G. E. Kalmus, D. S. Bailey, V.

Hagopian, N. N. Jew, and A. Kernan, Experimental Determination of $K^- n$ and $K^- d$ Elastic-Scattering Cross Sections in K^- Momentum Range 815 to 1115 MeV/c, Bull. Am. Phys. Soc. 11, 326 (1966).]

EXPERIMENTAL STUDY OF K_{e4} DECAY

Powell-Birge Group

The group is collaborating with University College, London, and the University of Wisconsin on scanning and analyzing approximately 570 000 pictures of stopping K^+ in the CERN heavy-liquid bubble chamber. The purpose of the experiment is to investigate the low-energy $\pi\pi$ interaction, using the rare decay mode $K^+ \rightarrow \pi^+ \pi^- e^+ \nu$.

Approximately half of the film has been scanned and measured. A total of ≈ 250 K_{e4} decays is expected.

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

$$K^+ \rightarrow \pi^0 e^+ \rightarrow 2\gamma \rightarrow 2(e^+ e^-).$$

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 γ rays from π^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.

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

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

This work has now been completed and the results are contained in a paper submitted to Phys. Rev. [G. Gidal, G. E. Kalmus, W. M. Powell, C. L. Sandler, R. T. Pu, et al.,

*Present address: University of California, Riverside.

Measurement of K^+ Decay Parameters
(UCRL-16593, January 3, 1966) submitted to
Phys. Rev.]

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

DATA REDUCTION

Robert W. Birge and P. Wesley Weber

Summary of Scanning and Measuring

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

Scanning			
Experiment	Bubble chamber	Beam	Number of frames
Conventional system			
29	20-inch deuterium (Brookhaven)	3.69-BeV/c deuteron	49 244
32	25-inch hydrogen	850- to 1150-MeV/c K^-	124 033
34	25-inch deuterium	850- to 1150-MeV/c K^-	459 584
35	1.1-meter CERN heavy liquid (C_2F_5Cl)	Stopping K^+	153 147
36	72-inch hydrogen	3.3-BeV/c π^+	3 021
38	72-inch hydrogen	3.5-BeV/c π^+	571
40	72-inch hydrogen	3.9-BeV/c π^+	192
		Subtotal	789 792
FSD system			
32	25-inch hydrogen	850- to 1150-MeV/c K^-	4 433
34	25-inch deuterium	850- to 1150-MeV/c K^-	2 314
36	72-inch hydrogen	3.3-BeV/c π^+	20 568
37	72-inch hydrogen	3.7-BeV/c π^+	12 371
38	72-inch hydrogen	3.5-BeV/c π^+	20 149
40	72-inch hydrogen	3.9-BeV/c π^+	389
		Subtotal	60 224
		Total	850 016

Measuring				
Equipment	Measuring hours	Number of events	Events per measuring hour	Measuring hours per 4032 hours
Microscope C	2311.8	11 816	5.1	0.53
Microscope E	1981.4	9 611	4.9	0.45
MP-1C	1708.1	7 441	4.4	0.39
MP-1D*	43.3	153	3.5	0.01
TOTAL	6044.6	29 021	4.8	0.35

* Acquired in April and converted to FOG format.

Computer-Controlled Data-Reduction System

Work is now in progress on a computer-controlled system which is designed to integrate our present system configuration to insure very rapid real time and efficient flow of bubble chamber measurements to a final analysis form. This result will be accomplished by interfacing measuring and scanning machines directly to an IBM 7044. The on-

line computer will acquire, arrange, and disseminate data either to magnetic tape or directly to a "large" computer. During this process, the measurements will be checked and error information transmitted to the measurer to indicate need for remeasurement. Additionally, the 7044 will sequence the measurements and control measuring-engine movement to permit automatic location of fiducials and events, thereby allowing an increase in measuring and scanning rates.

PHYSICS RESEARCH

Emilio Segrè and Owen Chamberlain in charge

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

The apparatus to detect an asymmetry of the form $\sigma_{\mu} \cdot P_{\pi} \times P_{\mu}$ in $K_{\mu 3}$ has been put into operation (in Beam #5) at the Bevatron. The number of K^+ that stop in the target of the apparatus amounts to about 700 per pulse under typical long-spill conditions. About 50 000 pictures of the spark chambers have been taken. The SPASS computer scanning system at MIT is analyzing the film for K^+ and μ^+ trajectories and for γ -ray showers from π^0 decay. The yield of completely determined $K_{\mu 3}$ events is not yet known.

PROTON-PROTON INTERACTIONS AT 6 BeV/c

W. Chinowsky, Robert R. Kinsey,
Stanley L. Klein, Mark A. Mandelkern,
Kwok M. Ong, and Jonas Schultz

Scanning and measurement of the 72-inch bubble chamber film is continuing. About 95% of the film has been scanned, and strange-particle production events have been measured in about three-fourths of these. Measurements of other events, by use of the FSD system, have proceeded more slowly. Only about 10% of the non-strange-particle events have been measured. It is expected that more effort will now be put into this program, with the strange-particle events requiring less.

The results still show no evidence of strong hyperon-nucleon final-state interactions in the range of effective mass $M_{YN} < 3.1 \text{ BeV}/c$. In the state $\Lambda^0 p K^+$ a strong peak in the $\Lambda^0 K^+$ mass distribution near $M_{\Lambda K}^* \approx 1700 \text{ MeV}/c^2$ is observed. It is not clear whether this represents a ΛK decay mode of the observed nucleon-pion resonance at $M_{N\pi}^* = 1688 \text{ MeV}$. The decay angular distribution indicates that the events are not the result of the decay of a pure state.

The observed distributions in Treiman-Yang angle and momentum transfer are in disagreement with the predictions of the one-pion exchange model, as is the small Λ^0 polarization. The four-body states show a dominance of $Y^*(1385)$ and $N^*(1238)$ production.

Based on a small sample of the data, the various final states among events with two-prong and neutral V^0 occur with the following relative frequencies.

1. Three-body states

$\Lambda^0 p K^+$	119 events
$\Sigma^0 p K^+$	35
$\Sigma^+ p K^0$	33

2. Four-body states

$\Lambda^0 p \pi^+ K^0$	116
$\Sigma^0 p \pi^+ K^0$	68
$\Lambda^0 p K^+ \pi^0$	77
$\Lambda^0 N K^+ \pi^+$	96
$pp K^0 \bar{K}^0$	7
$pN K^+ K^0$	21

3. Five-body (or more) states--174 events, of which 128 had Λ^0 decays, 46 K^0 decays.

These numbers have all been corrected for unobserved neutral decays. The total strange-particle production cross section is $400 \mu\text{b}$ to within an estimated $\pm 25\%$ uncertainty.

These results have been reported at the Washington, D. C. Meeting of the American Physical Society; see Chinowsky et al., Bull. Am. Phys. Soc. 11, 360 (1966).

 π -MESIC ATOMSDonald C. Girvin, David A. Jenkins,
Arthur R. Kunselman, Melvin K. Simmons,
and Toshimits U. Yamazaki

Work on π -mesic atoms in collaboration with Crowe's group has continued. Results up to now have been reported by Jenkins and Crowe, Phys. Rev. Letters 16, 637 (1966), and David A. Jenkins, Raymond Kunselman, Melvin E. Simmons, and Toshimits Yamazaki, $2p \rightarrow 1s$ x-Ray Transitions in π -Mesic Atoms, UCRL-16855, May 1966.

Targets for runs on compounds have been prepared.

K-MESIC ATOMS

Clyde Wiegand

An exploratory experiment to detect x rays from K-mesic atoms in light elements is in preparation.

POLARIZATION IN $\pi^- p$ ELASTIC SCATTERING
(229 TO 390 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

In an apparatus using a polarized proton target, the polarization in the elastic scattering of negative pions on protons was measured at 229, 318, and 390 MeV. The results are in fair agreement with phase-shift predictions of Roper and Bareyre et al. except at 318 MeV. At this energy, the data of Vik and Rugge show a polarization of about 0.6 at 120 deg c. m. scattering angle, our data show about 0.5, and the phase shift predictions are about 0.2. It is planned that our data be phase-shift analyzed by a program currently being developed.

POLARIZATION IN $\pi^+ p$ ELASTIC SCATTERING
(200 TO 300 MeV)

William Gorn, John E. Brolley,
Owen Chamberlain, Paul D. Grannis,
Leland E. Holloway, Charles C. Morehouse,
Peter R. Robrish, Stephen Rock,
and Herbert M. Steiner

We are preparing to make further measurements on polarization in positive pion-proton elastic scattering, in an experiment involving the polarized proton target. It is expected that much greater accuracy can now be achieved than was possible in earlier experiments. The expectations of improved accuracy are based on the attainment of higher values of the target polarization (typical average 55%), on more experience in the maintenance and use of the polarized target, and on more sophisticated counting equipment than was available some years ago, when an early version of the polarized target was used to study this same reaction.

POLARIZATION IN $\pi^\pm p$ ELASTIC SCATTERING
(500 MeV TO 3.5 BeV)

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

In this experiment, performed between October 1965 and March 1966, we have measured the asymmetry and hence polarization in $\pi^\pm p$ elastic scattering by using the Berkeley polarized proton target and a pion beam generated at the third focus of the Bevatron's external proton beam. We used several arrays of scintillation counters to measure the incoming pion lab angle and momentum and the lab angles of both the scattered meson and the recoil proton so that elastic scattering off the polarized free protons (3% by weight) in the target could be distinguished from all other scattering. A PDP-5 computer was used on-line to remember which of the some 110 counters possibly involved in a single event had actually fired. Its capacity was 128 events (each triggered by a sevenfold fast coincidence), which allowed beam intensities up to several million particles per pulse. Between pulses it did the more complicated processing, and performed enough simple bookkeeping to make possible continuous monitoring of all the counting electronics.

Data were taken at a total of 13 different π^- beam momenta: 522, 596, 671, 745, 820, 895, 1155, 1352, 1988, 2535, 2912, 3260, and 3747 MeV/c; and 15 π^+ momenta: 745, 895, 1024, 1085, 1155, 1284, 1352, 1441, 1570, 1690, 1896, 1988, 2335, 3260, 3747 MeV/c. There was also a calibration run based upon the pp polarization at 1400 MeV/c. Altogether, the target was polarized for 120 Bevatron periods, and about 22 million events were recorded on 120 magnetic tapes.

Preliminary processing on the 7094 of all these data has been completed and some results reported by Leland Holloway at the American Physical Society Meeting in New York during January 1966 [Bull. Am. Phys. Soc. 11, 118 (1966)].

More complete analysis on the 6600, including corrections for momentum spread in the beam, target polarization variations,

etc., is in progress now. Also being developed are programs to use these data to attempt to extend πp phase-shift analysis into the 1- to 2-GeV/c range.

INTRINSIC RELATIVE PARITY OF THE $K-\Sigma-N$ SYSTEM

Byron 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 consists in the measurement of the azimuthal asymmetry in a state $K^+ + \Sigma^+$ produced by the collision of 1150-MeV/c π^+ with protons in a polarized hydrogen target. The algebraic sign of the K^+ production asymmetry in the plane normal to the proton spin direction, when compared with polarization values for the same reaction as measured in bubble-chamber experiments, gives the $K\Sigma N$ parity.

Of the 50 000 spark chamber events 11 000 have been selected by scanning and have been measured. Computer analysis yielded about 2700 K^+ events satisfying rigid selection criteria. This initial analysis showed a need for better beam-momentum resolution to improve the kinematic separation of the K^+ events involving free hydrogen from those produced in the heavy elements of

the target. A program to measure the π^+ momenta for those events in which there is more than one track in the beam spark chambers has been started and is about 50% completed. Beam momentum measurements are continuing for the remainder of the data and should be finished shortly. We are attempting to use a Monte Carlo program to understand more completely the nature of the background, and we are analyzing the events produced in a hydrogen-free "dummy" target.

POLARIZATION OF THE Σ^- IN THE PROCESS $\pi^- + p \rightarrow \Sigma^- + K^+$

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

Measurements will be completed shortly of spark chamber pictures taken in a polarized target experiment designed to measure the polarization of the Σ^- hyperon produced by π^- mesons of momentum 1150 MeV/c. Approximately 300 pictures out of 1300 remain to be measured. An estimated 100 elastic hydrogen events are expected in the sigma center-of-mass angular region 140 to 180 deg. An equal number of quasi-elastic background events is also expected.

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 which are measured on free radioactive atoms in a beam include nuclear spins, nuclear magnetic dipole and electric quadrupole moments, atomic hyperfine structures, hyperfine-structure anomalies, electronic angular moments, 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.

PAPERS ISSUED

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

Articles

1. Richard D. Worley, Vernon Ehlers, William A. Nierenberg, and Howard A. Shugart, Hyperfine-Structure Separation, Nuclear Magnetic Moment, and Hyperfine-Structure Anomaly of Cesium-131, *Phys. Rev.* 140, B1483 (1965).
2. Tetsuo Hadeishi and William A. Nierenberg, Direct Observation of Quantum Beats Due to Coherent Excitation of Nondegenerate Excited States by Pulsed Electron Impact, *Phys. Rev. Letters* 14, 891 (1965).
3. Richard Marrus and Joseph Yellin, Optical Pumping Transients in Rubidium-87 and Application to Disorientation Cross Sections, *Phys. Rev.* 141, 130 (1966).
4. Richard G. Schlecht and Douglas W. McColm, Hyperfine Structure of the Stable Lithium Isotopes. I, *Phys. Rev.* 142, 11 (1965).
5. Douglas McColm, Hyperfine Structure of the Stable Lithium Isotopes. II, *Phys. Rev.* 142, 14 (1965).
6. Barbara M. Dodsworth and Howard A. Shugart, Nuclear Spin, Hyperfine Structure, and Magnetic Moment Investigations on Cu^{61} ,

- Cu^{62} , and Cu^{64} , *Phys. Rev.* 142, 638 (1966).
7. Howard A. Shugart, Direct Measurements of Spins of Radioactive Nuclei, UCRL-16547, Dec. 1965.
8. Y. W. Chan, V. J. Ehlers, and W. A. Nierenberg, The Nuclear Spin and Magnetic Dipole Moment of 39-min Gold-190, *Phys. Rev.* 144, 1020 (1966).
9. Rodney C. Greenhow and Robert J. Hull, Adjustments of Narrow-Band Ultraviolet Fabry-Perot Interferometers, UCRL-16590, Dec. 1965.
10. Howard A. Shugart, Atomic and Molecular Beams, in *The Encyclopedia of Physics*, R. M. Besancon, editor (Reinhold Publishing Co., New York, 1966).
11. Tetsuo Hadeishi and Chung-Heng Liu, Intensity Beats in Resonance Radiation Absorbed by a Coherently Excited Metastable State, UCRL-16731, March 1966.
12. Hyatt M. Gibbs and Eugene D. Commins, A Large-Aperture High-Efficiency Ion Detector, UCRL-16714, Feb. 1966.
13. R. C. Barrett, Isotope and Isomer Shifts in Mercury, UCRL-16732, March 1966.
14. Tetsuo Hadeishi, Experiments on Electronic Excitation of Atoms Performed at the Lawrence Radiation Laboratory, Berkeley, California, USA, UCRL-16742, March 1966.
15. Richard Marrus and Douglas McColm, Atomic Beam Method for the Study of Isotope Shifts, *Phys. Rev. Letters* 15, 813 (1965).
16. Lloyd Armstrong, Jr., Relativistic Effects in Atomic Fine Structure, UCRL-16670, Jan. 1966.
17. Richard Marrus, Douglas McColm, and Joseph Yellin, Atomic Beam Study of the Stark Effect in the Cesium and Rubidium D Lines, UCRL-16541, Dec. 1965.

Abstracts

1. Lloyd Armstrong, Jr., Relativistic Effects in the Hyperfine Structure of Pu, *Bull. Am. Phys. Soc.* 10, 1214 (1965).
2. R. J. Hull and L. C. Bradley, Measurements of Absorption-Line Profiles with a Fabry-Perot Interferometer, *J. Opt. Soc. Am.* 55, 1584 (1965).
3. Roger C. Barrett, Shell Model Calculations of the Isotope Shift in Heavy Nuclei, *Bull. Am. Phys. Soc.* 11, 56 (1966).
4. Lloyd Armstrong, Jr., and Richard Marrus, Nuclear Moments of Americium-241 and 16-hr Americium-242 and Analysis of the Hyperfine Fields, *Bull. Am. Phys. Soc.* 11, 121 (1966).
5. Joseph Yellin, Richard Marrus, and Douglas McColm, Atomic Beam Study of the

Stark Effect in Cesium and Rubidium D Lines,
Bull. Am. Phys. Soc. 11, 327 (1966).
6. Paul A. Vanden Bout, Vernon J. Ehlers,
William A. Nierenberg, and Howard A.
Shugart, The Hyperfine Structure Anomalies
of Au-¹⁹⁸ and Au-¹⁹⁹, Bull. Am. Phys.

Soc. 11, 343 (1966).

Thesis

1. Lloyd Armstrong, Jr., Nuclear Magnetic
Moments and Hyperfine Anomalies of Re¹⁸⁶,
Re¹⁸⁸, and Am²⁴¹, Am²⁴², (Ph. D. thesis)
UCRL-16419, Sept. 1965.

PHYSICS RESEARCH

George H. Trilling and Gerson Goldhaber in charge

The experimenters involved in this work are Roger W. Bland, Ian Butterworth, Jonathan Chan, Jan D. Dash, Chu-min Fu, Gerson Goldhaber, Sulamith Goldhaber,* Medhi Golshani, Allan A. Hirata, John A. Kadyk, James MacNaughton, Yona Oren, Benjamin C. Shen, Bertram M. Schwarzschild, Victor H. Seeger, and George H. Trilling.

 K^+ p INTERACTIONS AT 4.6 BeV/c

We have continued analysis of approximately 50 000 photographs of the 80-inch Brookhaven National Laboratory hydrogen bubble chamber exposed to a 4.6-BeV/c K^+ meson beam. Both the automatic measuring machine, the Flying Spot Digitizer, and the Franckenstein have been employed in measurement. We have identified the reactions

$$K^+ + p \rightarrow K^0 + \pi^+ + p, \quad 281 \text{ events}, \quad (1)$$

$$K^+ + p \rightarrow K^0 + \pi^+ + \pi^0 + p, \quad 454 \text{ events}, \quad (2)$$

and

$$K^+ + p \rightarrow K^+ + \pi^- + \pi^+ + p, \quad 997 \text{ events}. \quad (3)$$

In all these reactions $K^*(1400)$ production is observed. The distribution in the $K\pi$ scattering angle for $K^*(1400)$ shows characteristic features expected for an aligned 2^+ meson on a one-pion-exchange model. The $K^*\pi$ enhancement at 1320 MeV, $K^{**}(1320)$, is observed in Reactions (2) and (3). If the enhancement is treated as a kinematic consequence of $K^*\pi p$ formation the behavior of the πp scattering angle in the πp rest frame is reminiscent of diffraction scattering. The decay angular distributions of $K^*(890)$ in the $K^*(1320)$ band exhibit alignment characteristic of the peripheral production of $K^*(890)$ via one-pion exchange.¹

We are also studying the production dynamics of the quasi-body reactions

$$K^+ + p \rightarrow K^{*+} + p \quad 84 \text{ events}, \quad (4)$$

$$K^+ + p \rightarrow K^0 + N^{*++} \quad 71 \text{ events}, \quad (5)$$

$$K^+ + p \rightarrow K^{*0} + N^{*++} \quad 174 \text{ events}. \quad (6)$$

*Deceased.

1. S. Goldhaber, J. L. Brown, I. Butterworth, G. Goldhaber, B. C. Shen, C. M. Fu, and G. H. Trilling, Talk presented by Sulamith Goldhaber at the Oxford International Conference, September 1965 (UCRL-16332 Rev.).

From the analysis of the decay angular distributions, we find that Reactions (4) and (5) are mainly dominated by vector meson exchange, whereas Reaction (6) proceeds predominantly via one-pion exchange.

Reactions leading to more complex final states as well as associated production are currently being studied.

THE K^+ p AND K^+ d INTERACTIONS IN THE MOMENTUM RANGE 0.86 TO 1.58 BeV/c

In our study of K^+ interactions in hydrogen we have measured about 9000 inelastic events, at beam momenta of 0.86, 0.96, 1.2, 1.28, 1.36, and 1.58 BeV/c, and about 30 000 elastic scatterings at 0.86, 0.96, 1.2, and 1.28 BeV/c.

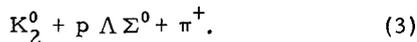
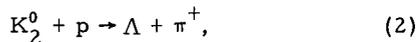
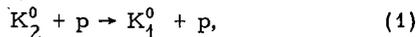
The inelastic channels in hydrogen are dominated in this energy range by the reaction $K^+p \rightarrow KN\pi$, and the reaction proceeds almost exclusively through the intermediate quasi-two-body states $K+N^*(1236)$ and $K^*(891) + N$. The N^* seems to be produced by ρ exchange with magnetic dipole coupling at the $\rho p N^*$ vertex, and the K^* is produced largely by vector meson exchange. Application of a simple absorption model to the single-particle-exchange model predictions seems to give a reasonable description of the inelastic channels in the energy range studied. The K^+p elastic scattering data are under study, but their analysis is not complete.

The measurement of K^+d interactions also obtained in the course of the same exposure has been under way for a few months. Inelastic events at 1.58 BeV/c have been measured, and we are now beginning the processing of events at 1.2 BeV/c. The recent discovery of Cool et al.² of structure in the K^+p and K^+d cross sections near 1.2 BeV/c makes this work of particular interest.

2. R. L. Cool et al., Postdeadline Paper, Washington Meeting APS, 1966.

STUDY OF K_2^0 DECAYS AND INTERACTIONS

The study of K_2^0 decays and interactions has been continued. The main effort has been devoted to the study of the strong interactions



Of the events measured until now (about 1/3 of the total), 1250 events, which are well measured and inside a fiducial volume, have been accepted for further analysis. The events are divided about equally among the three channels. One of the more striking results is the substantial asymmetry observed in the angular distribution for Reaction (2). Reaction (1) shows a smaller asymmetry, and Reaction (3) shows no asymmetry at all. The asymmetry in the Λ - π channel is due to p wave whose amplitude relative to the s wave is about 10 to 20% over the whole momentum range (K_2^0 momentum 150 to 500 MeV/c). The two amplitudes are almost in phase, as there is no appreciable polarization of the Λ 's. The presence of the p wave can be explained by the tail of $Y_1^*(1385)$. The theoretical predictions and experimental magnitudes disagree by a factor of the order of 2, which may be caused by the lack of a good theoretical understanding of the behavior of a resonance several half widths away from its peak.

Several thousand K_2^0 decays have been measured and are presently being analyzed.

PAPERS ISSUED

Talks

1. George H. Trilling, K Decay, presented at the International Conference on Weak Interactions, Argonne National Laboratory, October 1965 (UCRL-16473, November 1965).
2. John A. Kadyk, Low Energy Interactions between Protons and K_2^0 Particles, invited paper presented at the 1966 Washington APS Meeting, April 1966.
3. Sulamith Goldhaber, A Review of Recent Boson Resonances, invited Lecture Series presented at the 5th Session of the Spring School of Experimental and Theoretical Physics, Nor-Hambert, Erevan, Armenia-May 1965 (UCRL-16295, May 1965).
4. Sulamith Goldhaber, J. L. Brown, I. Butterworth, G. Goldhaber, B. C. Shen, C. M. Fu, and G. H. Trilling, K_2^+p Interaction at 4.6 BeV/c (UCRL-16332, February 1966), presented at the 1965 Oxford International Conference on Elementary Particles, Oxford, England, September 1965.

5. Gerson Goldhaber, B. C. Shen, J. L. Brown, G. Goldhaber, S. Goldhaber, and G. H. Trilling, Diffraction Scattering of Virtual Pions and the A_1 Enhancement (UCRL-16392, September 1965), presented at the 1965 Oxford International Conference on Elementary Particles, Oxford, England, September 1965.
6. Michael G. Bowler, R. W. Bland, J. L. Brown, G. Goldhaber, J. A. Kadyk, V. Seeger, and G. H. Trilling, Study of the Reaction $K_2^+p \rightarrow K + N + \pi$ between 0.86 and 1.58 BeV/c (UCRL-16370, September 1965), presented at the Oxford International Conference on Elementary Particles, Oxford, England, September 1965.

Abstracts

1. Roger W. Bland, M. G. Bowler, J. L. Brown, G. Goldhaber, J. A. Kadyk, V. Seeger, and G. H. Trilling, "Study of the Reaction $K_2^+p \rightarrow K + N + \pi$ between 0.86 and 1.58 BeV/c," Bull. Am. Phys. Soc. II, 11, 76 (1966). R. Bland presented lecture at the 1966 Annual Meeting of the APS at New York, 1965.
2. G. H. Trilling, R. W. Bland, M. B. Bowler, J. L. Brown, S. Goldhaber, G. Goldhaber, J. A. Kadyk, V. H. Seeger, " $K_2^+p \rightarrow K_1^0 \pi^+$ at 1.58 BeV/c," Bull. Am. Phys. Soc. II, 10, 680 (1965). G. H. Trilling presented talk at Hawaii September 1965 Meeting.
3. I. Butterworth, J. L. Brown, G. Goldhaber, S. Goldhaber, A. A. Hirata, J. A. Kadyk, B. C. Shen, B. M. Schwarzschild, G. H. Trilling, " K_2^+d Interaction at 2.3 BeV/c," Bull. Am. Phys. Soc. II, 10, 680 (1965). G. H. Trilling presented at Hawaii APS September 1965 Meeting.
4. B. C. Shen, I. Butterworth, J. Dash, C. M. Fu, G. Goldhaber, S. Goldhaber, and G. H. Trilling, " K_2^+p Interaction at 4.6 BeV/c," Bull. Am. Phys. Soc. II, 11, 77 (1966). B. Shen presented talk at the 1966 Annual Meeting of the APS at New York. (January 1966)
5. J. A. Kadyk, Y. Oren, R. Brower, J. L. Brown, I. Butterworth, G. Goldhaber, S. Goldhaber, J. MacNaughton, B. C. Shen, G. H. Trilling, " K_2^0p Interaction at Low Energy," Bull. Am. Phys. Soc. II, 11, 37 (1966-New York Meeting).

Articles

1. B. C. Shen, G. Goldhaber, S. Goldhaber, J. A. Kadyk, Phys. Rev. Letters 15, 731 (1965).
2. G. H. Trilling, J. L. Brown, G. Goldhaber, S. Goldhaber, J. A. Kadyk, J. Scanio, Physics Letters 19, 427 (1965).
3. I. Butterworth, J. L. Brown, G. Goldhaber, S. Goldhaber, A. A. Hirata, J. A. Kadyk, G. H. Trilling, Phys. Rev. Letters 15, 500 (1965).

4. G. Goldhaber, S. Goldhaber, J. A. Kadyk, B. C. Shen, Phys. Rev. Letters 15, 118 (1965).
5. S. Goldhaber, W. Chinowsky, G. Goldhaber, T. O'Halloran, Phys. Rev. 142, 913 (1965).
6. S. Goldhaber, J. L. Brown, I. Butterworth, G. Goldhaber, A. A. Hirata, J. A. Kadyk, G. H. Trilling, Phys. Rev. Letters 15, 737 (1965).
7. D. E. Dorfan, J. Eades, L. M. Lederman, W. Lee, C. C. Ting, P. Piroue, S. Smith, J. L. Brown, J. A. Kadyk, G. H. Trilling, Phys. Rev. Letters 14, 995 (1965).
8. W. Chinowsky, S. Goldhaber, G. Goldhaber, T. O'Halloran, B. M. Schwarzschild, Phys. Rev. 139, B1411 (1965).

DATA HANDLING

Howard S. White in charge

COMPUTER PROGRAM DEVELOPMENT

HAZE

The ability to detect transient hardware failures with immediate remeasurement in the main HAZE program (420) was debugged and implemented. This procedure substantially improves the event-measurement efficiency.

Program 420 was modified to process very short tracks by using the scan table digitizations of the beginning and end points directly. This procedure does not permit determination of momentum from curvature. However, since most short tracks stop inside the chamber, the momentum information can be computed from the track length. This procedure not only improves the event-measurement efficiency, but also eliminates a source of bias in the rejected events.

The ionization algorithm was improved for tracks which pass through flares and otherwise obscured regions of film.

A learning procedure for computing missing fiducials was designed and implemented. The program uses fiducial locations that have been determined on the basis of current experience in nearby frames to supply computed values of the missing fiducials. This technique has almost entirely eliminated one source of HAZE rejections, which has been common in a large fraction of the film measured to date.

Measurement of new experiments in the Berkeley 25-inch and 72-inch chambers and the Brookhaven 80-inch chamber was started. (Joyce Crawford)

The FSD format and hardware checking program (431) was debugged, and placed in routine use as a quality monitor for the FSD. The program is run prior to each large production run, and produces an on-line summary so that the presence of any serious component failures or machine maladjustment can be detected.

Code was started for Program 434, a calibration program for the FSD, which utilizes both the fiducial finding subroutines of the HAZE program and a precision test pattern. This program will greatly reduce the tedious effort now required to calibrate the FSD by hand. (Bud Koger)

Work was started on a modification to the scan-tape editing program (422) to accept an event identification record. This record can be used by DAPR for measuring sparse events efficiently. It is also useful to the HAZE-mode operations by providing a mechanism for entering into the bookkeeping system events whose measurement is not desired. (Carol Osborne)

FOG

The three-view FOG program (140), an extension of the two-view FOG program (135), was placed in preliminary production status and shakedown runs were begun.

This program can process two-point track measurements. The program reconstructs the points in space which best correspond to the measured film coordinates in all three views in a least-squares sense. The track direction is then determined from the end points, and the momentum may be determined from the track length.

The program also contains an improved optical model. This model was developed by Frank Solnitz of the Alvarez group in an attempt to remove some of the more glaring inconsistencies in the 72-inch chamber optics. Although this model is an improvement over the original, it is felt that further development will be necessary.

A diagnostic program (141) which shows the displacement in film of the measured points from the projected optimum orbit was written and debugged. This program has provided valuable insight into the sources of error in HAZE measurements. (Dennis Hall, Joan Franz, Frank Windorski)

CLOUDY

An improved special-purpose constraints subroutine was written and partially debugged. The purpose of this subroutine is to treat those events which have zero degrees of freedom in a more general way so that a solution will be obtained for those events which initially have no solution.

Additional format modifications for the three-view library format were incorporated in the CLOUDY system.

New assignment lists were set up in all

experiments, and several special-purpose modifications were implemented to handle event topologies which are normally not considered.

A new experiment was set up in the collaboration of the Powell-Birge group with the Barkas group at UCR. The events are measured at Riverside and the data are sent to Berkeley. The measurements are processed through the FOG and CLOUDY programs and the reduced data are sent back to Riverside for further processing. (Vivian Morgan)

FAIR

The FAIR abstraction program (304) was extended to include all three-view FOG parameters.

The FAIR output program (305) was modified to run more efficiently, by better allocating storage assignments. This modification has substantially improved the running time for FAIR jobs.

The FAIR library merge program (311) was put into production and modified to produce a summary report for the resulting output library.

A special-purpose subroutine was written for the Trilling-Goldhaber group to provide final event identification by physicists on the FAIR library.

A special-purpose calculation was written for the Segrè-Chamberlain group to provide a more accurate ionization estimate.

Work continued on flow charting for a reassembly of program 304 during this period. (Loren Shalz)

TRIST

Routine running of A- and C-priority programs continued. A new assembly of TRIST was started. This assembly will include B-level logic, communication links for

TRIST-DAPR operation, logic for a tandem FSD, and a special disk routine which will handle data storage and disk location information for both A and B levels. (Carol Osborne)

EVENT ACCOUNTING

A program (435) to provide an event accounting source tape of scanning information was written, debugged, and documented. This program provides the necessary first step in producing event-accounting information. (Carol Osborne)

The event-accounting procedure was implemented by the completion of programs 605A and 602A. Program 605A generates an unpacked event-accounting source (EAS) tape for a FOG library tape and an auxiliary data tape. This EAS tape contains all the pertinent scan data, measured data, and reconstruction data for each event on the FOG library tape. The EAS tapes, whether produced by program 605A or by the Standard FCF production programs, are processed by Program 602A, which packs the data, merges all data pertaining to the same physical event, and writes a Packed Event-Accounting Source (PEAS) tape for each experiment referred to on the EAS tape.

Program 603A, which will merge PEAS tapes, making a master PEAS tape for each experiment, is being written currently. (Shirley Buckman)

DAPR

Flow charts were completed for the DAPR production system, and coding was started. Coding on the main abstraction program was completed and debugging was started. Coding on the B-level programs was in its early stages. (Joan Tyson, David Budenears, Nan Jontulovic)

DATA PROCESSING OPERATIONS

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

Chamber (and laboratory, if other than LRL)	Event Measurements Analyzed		Number of events
	Beam	Group	
<u>Franckenstein measurements</u>			
30-inch propane	Stopping K^+	Powell-Birge	3 148
20-inch deuterium BNL	3.7-BeV/c D	Powell-Birge	1 302
25-inch hydrogen	0.8-1.2-BeV/c K^-	Powell-Birge	8 721
25-inch deuterium	0.9-1.2-BeV/c K^-	Powell-Birge	25 634
100-cm propane/freon, CERN	Stopping K^+	Powell-Birge	343
72-inch hydrogen	3.3-BeV/c	Powell-Birge	102
			<u>39 250</u>
<u>FSD Measurements</u>			
04 25-inch hydrogen chamber	1.2-BeV/c K^+	Trilling-Goldhaber	215
05 25-inch hydrogen chamber	1.4-BeV/c K^+	Trilling-Goldhaber	1 955
07 25-inch hydrogen chamber	0.8-BeV/c K^+	Trilling-Goldhaber	399
09 80-inch hydrogen chamber, BNL	4.0-BeV/c K^+	Trilling-Goldhaber	21 390
10 80-inch hydrogen chamber, BNL	4.0-BeV/c K^+	Trilling-Goldhaber	6 878
11 25-inch hydrogen chamber	0.3-BeV/c K_2^0	Trilling-Goldhaber	2 783
12 25-inch deuterium chamber	1.2-BeV/c K^+	Trilling-Goldhaber	5 562
32 25-inch hydrogen chamber	0.8-1.4-BeV/c K^-	Powell-Birge	5 403
34 25-inch deuterium chamber	0.8-1.4-BeV/c K^-	Powell-Birge	159
36 72-inch hydrogen chamber	3.3-BeV/c π^+p	Powell-Birge	7 264
37 72-inch hydrogen chamber	3.7-BeV/c π^+p	Powell-Birge	575
38 72-inch hydrogen chamber	3.5-BeV/c π^+p	Powell-Birge	3 785
70 72-inch hydrogen chamber	6.0-BeV/c p	Segrè-Chamberlain	10 730
			<u>67 098</u>
		Total events analyzed	<u>106 343</u>

HEALTH PHYSICS

H. Wade Patterson in charge

RADIATION STUDIES

At the Bevatron, external-beam radiation studies have been made to aid us in advising on the design of the permanent external-beam channel and backstop.

We have also studied the production of sodium-24 in concrete. We have exposed samples of aggregate and the elemental constituents of aggregate at different depths, in pairs of special concrete blocks of very different boron concentration. As a monitor of Bevatron operation during the activation, we use the production of sodium-24 in aluminum and of beryllium-7 in water.

DETECTORS

Methods of extracting pulse information

from our large-area ($32\,000\text{ cm}^2$) bismuth fission counters have been studied and compared with delay-line coupling of the 21 parallel-plate sections. The insertion loss of each section (200 pF) into the delay line ($z = 1000\Omega$) nearly equals the loss of signal amplitude when all sections are connected in parallel with the delay line omitted. Parallel connection results in an improvement in signal-to-noise ratio of nearly 2:1; however, pulse rise time is adversely affected, increasing from 0.2 to 1 μsec .

The formation of Tb^{149} , an α -emitter of 3.95 MeV and 4.1-hour half life, by interaction of high-energy neutrons and protons ($E \geq 600\text{ MeV}$) with mercury is being studied as a possible threshold detector for Health Physics purposes.

ACCELERATOR OPERATION AND DEVELOPMENTACCELERATOR STUDY GROUP

Edward J. Lofgren in charge

The Accelerator Study Group continued design of the 200 BeV Accelerator. A "Preliminary Project Report" was issued in January 1966, recording the changes in design that occurred after the June 1965 Design Study. The work toward the Preliminary Project Report was aided by personnel from DUSAF, a joint venture of four architectural-engineering firms. DUSAF issued a separate Preliminary Project Report discussing design of conventional facilities and cost estimates.

Members of the Accelerator Study Group participated in a technical panel convened by the National Academy of Sciences Site Evaluation Committee. This panel explored the design and operational differences

between sites proposed for the 200 BeV accelerator. Members of the Accelerator Study Group also participated in public discussions of design alternatives for the accelerator. As a result of these discussions, the intensity and scope proposed for the 200 BeV accelerator by the Study Group have been endorsed by a number of the high-energy physicists of the United States.

The group is continuing studies of injection methods, surveying methods, and beam-extraction problems. Computation of magnetic fields has been advanced, and has been carried out for many cases to refine the design of the magnets proposed for the accelerator. Experimental studies of radio-frequency acceleration structures were also continued.

BEVATRON

Edward J. Lofgren in charge

OPERATION AND DEVELOPMENT

The Bevatron beam was operational for experimenters 87% of the scheduled time. Two basic modes of operation were established for the operation of six secondary beam channels. The two modes were: (a) 6.1 BeV with a 300-msec flat top, and (b) 5.3 BeV with a 900-msec flat top. Both these modes involved simultaneous operation for five or six separate beam channels. Two of these secondary beam channels were from targets inside the Bevatron and four from targets in the external proton beam.

During the second half of 1965 a beam loss 40 to 50 msec after injection occurred sporadically. It was determined that changes in pole-face winding currents were in part responsible for this loss. By changing to a set of operating values used previously, we were able to eliminate this sporadic loss. We subsequently discovered damage to the epoxy coil potting on the septum of the first magnet in the external proton beam extraction system. It was not clear whether it was a radiation, thermal, or potting problem, aggravated by the proton beam striking the septum. Thus far, this damage has not interfered with operation of this magnet.

Noise pickup problems were eliminated in the Bevatron beam induction-electrode system by the installation of a new cathode-follower circuit. This permitted the use of the radius feedback system (autotrack) to control the radial position of the beam during acceleration. The Autotrack system is necessary for beam tracking through the new modes of magnet pulsing known as "mezzanine." Final tests of this mode of pulsing were made, and use of the mezzanine is now an operating mode at the Bevatron.

More complete details of operation for this period are given in the quarterly reports, Bevatron Operation and Development, Numbers 48 and 49.^{1, 2}

1. Kenneth C. Crebbin, Bevatron Operation and Development 48, UCRL-16741, March 1966.
2. Kenneth C. Crebbin, Robert Frias, and Fred H. G. Lothrop, Bevatron Operation and Development 49, UCRL-16809, May 1966.

In March 1965 construction began on the new craneway that will service the existing backstop area of the external beam channel as well as a major fraction of Bevatron secondary beams and experiments. The craneway is expected to be completed in October 1966.

Design work is in progress for the modified dual external beam channels and backstop areas as well as increased shielding to accommodate safely the present EPB intensity. The branching of the EPB channel allows operation in one channel with setup or maintenance in the other--hence increased operational efficiency. The dual channels will also provide greater flexibility for simultaneous running of the increasing number of experiments. The optical properties of the external beam will also be improved in this modification.

INFORMATION FOR EXPERIMENTERS

The first Bevatron Experimenters' Meeting was held on December 18, 1965. Its purpose was to acquaint the increasing number of Bevatron users with the Bevatron operations, equipment, support facilities, safety regulations, and general policies with regard to users. Current topics in high energy physics were discussed together with the existing Bevatron program and schedule of experiments. Future Bevatron developments were discussed, particularly with regard to improved external-beam extraction efficiency, improvements in the external beam channels for higher-intensity operation, and increased efficiency in compatible multi-experiment operations. Approximately 225 people attended this meeting from all parts of the U. S.

A Bevatron Experimenters' Handbook was distributed to the experimenters at the meeting. This book summarized general information about the Bevatron and its facilities. The important operational characteristics were listed in detail. This handbook also described the existing secondary beams available at the Bevatron and presented a complete survey of major Bevatron equipment, including detailed magnetic measurements for most Bevatron auxiliary magnets.

BOOKLET AND PAPER ISSUED
Bevatron Experimenters' Handbook, Dec. 1966.

Fred H. G. Lothrop, Bevatron Beam Spill by
Amplitude Modulation (UCRL-16219, Sept.
1965), submitted to Rev. Sci. Instr.

184-INCH CYCLOTRON

David L. Judd in charge
Reported by James T. Vale

No report was written for this Semiannual Report.

88-INCH CYCLOTRON

H. E. Conzett in charge

OPERATION

The distribution of cyclotron time during the period November 1965 through April 1966 was:

	Number of 8-hr shifts	% of time
Nuclear reactions and scattering research	203	44
Biomedical research	12	3
Cyclotron research	93	20
Isotope production	74	16
Preventive maintenance and scheduled shutdowns	72	15
Repairs (unscheduled shutdowns)	10	2
Total	<u>464</u>	<u>100%</u>

CYCLOTRON RESEARCH
AND DEVELOPMENT

A remote gas-feed system, which allows the changing of the ion source gas to be done from the control room, was put into operation. Six new trim coil power supplies were installed so that each of the 17 trim coils can now be adjusted separately. Tests were made and equipment has been ordered to provide NMR stabilization of the switching magnet.

Development of new beams continued. Energies now available are: protons from 10 to 55 MeV, α particles from 15 to 130 MeV (deuterons at half these energies), and He^3 from 10 to 145 MeV. Third-harmonic acceleration is used for α particles of less than 24 MeV and for He^3 of less than 18 MeV. Beam intensities are about 50% of those for normal first-harmonic operation.

Studies have been made of external beam quality and extraction efficiencies. The best deflector transmissions obtained with the old deflector were 60% on a 65-MeV α beam and 70% on a 120-MeV α beam. Emittance measurements gave a value of about 50 mm-mr horizontally, the same as measured previously.

Line 4 in the cyclotron vault was used for studies of energy spread and phase width of the external beam; since this line is a continuation of the staging line straight through the switching magnet, it is useful for the study of the "raw" beam from the cyclotron. A phase probe and a scattering foil with a semiconductor detector are available on this line, and an X collimator has been provided to permit studies of the energy dispersion of the deflection system and the cyclotron fringe field.

Continued studies have been made of the effects of various machine parameters on the energy and phase widths of the external beam. The beam is sensitive to dee voltage and frequency variations, so it has been seen that the dee voltage should be regulated to 0.1% and the frequency to 0.002% for stable operation.

The new regenerative deflection system was installed during November 1965. After 3 days of testing with beam, there were six energies of alpha beams developed between 23 and 130 MeV. After several weeks of operation the system was removed to permit indicated modifications to be made. It will be reinstalled in May 1966, and continued investigations are expected to result in continued improvement of its operation.

The full-scale model of the axial-injection system was successfully tested in the cyclotron. External cyclotron beams were achieved, even though only one day was available for the test run.

Three invited papers and four contributed papers will be presented at the International Conference on Isochronous Cyclotrons, Gatlinburg, May 1966.

EXPERIMENTAL RESEARCH

Beams of protons, deuterons, He^3 , and He^4 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.

ELECTRON LINEAR ACCELERATOR

David L. Judd in charge
Reported by Douglas W. Pounds

OPERATION

During the period November through April the group utilization of the Linac was as follows:

Group	Hours
Biomedical Research	276
Physics-Alvarez	192
Physics-Judd-Ruby	40
Health Physics	24
Chemical Biodynamics	104
Nuclear Chemistry	24
Ames Research Center (NASA)	8
Soil Sciences	2
Total	670

Available hours (one man for one shift):

6 months \times 4-1/3 weeks \times 40 hours -- 1040

Minus	Holidays	48 hrs	
	Vacation	48 hrs	
	Sick Leave	8 hrs	
	Total		-104

Net hours available 936

Utilization of the available machine time for experimenter irradiations (670/936) \approx 72%

The remainder of the time was devoted to Linac development, general duties, and maintenance, in that order.

Machine modifications for this period were limited to minor changes in control electronics.

RESEARCH PROGRAMS

The research programs carried on by experimenters during this period included studies of spectra of radicals at 4.2°K, studies of spectra of radicals at 77°K, irradiation of enzyme systems (mechanism of radiation damage and inactivation studies), ghost irradiations of blood cells, irradiation of prebiotic earth atmosphere for chemical evolution studies (origin of life), irradiation of expected Martian atmosphere for chemical evolution studies, D. N. A. irradiations for

study of mechanism of damage to living cells, organic compound irradiations, organic molecule yields from irradiated frozen methane, total sterilization of high-ferric-content soils (Martian soil studies), sterilization studies of soil organisms, development work on rf cavity photo multipliers, short-lived decay studies by neutron activation, Linac development studies.

Detailed reports describing the results of these studies are contained within the annual reports of the respective department.

LINAC RESEARCH AND DEVELOPMENT

As a result of the expressed interests of several of the utilizing groups, the author has conducted a study of the scope and techniques of pulse radiolysis systems. The study consisted of a survey of the recent publications and a visit to the Argonne National Laboratory, where a group headed by Dr. Edward Hart is making a major contribution in this area. The conclusions of the study are that pulse-radiolysis systems have broad application as a research tool, they seem to be destined for long-term usefulness, and they are well mated with an electron linear accelerator. As an example, the major use of the Argonne electron linac is pulse-radiolysis programs, and on the strength of these programs, Argonne Laboratory has acquired funds for a new \$800 000 Arco electron linac.

Argonne's pulse-radiolysis research to date has been carried out on their existing electron linac, which has rise and fall time, 0.4 μ sec each; peak current, 150 mA; 16 MeV maximum energy. Their new linac was purchased for the fast rise and fall time of 5 nsec each and the high peak current of 5 A. Their new machine gains for them the capability of investigating the shorter-lived radicals while continuing their studies of the 1- μ sec or longer decay lives.

The Berkeley electron linac's present capability of 0.2 μ sec rise or fall time, 175 mA, and 8 MeV will allow pulse-radiolysis systems to operate in this 1- μ sec or longer region. This region is still largely uninvestigated, and offers many research projects.

To initiate pulse-radiolysis studies at Berkeley, Warren Garrison's group from Nuclear Chemistry is assembling a system

to begin working with these μsec or longer radical species.

The author, in conjunction with the Linac Development program, also proposes to enter the pulse-radiolysis field. The Linac's aim will be the development and refinement of techniques to extend the capability of the Linac's pulse-radiolysis systems into the subnanosec region. This development program will be directed toward the eventual goal of observing the process of formation of radical species.

The buildup of radical products is believed to occur within an interval of the order of 10^{-11} sec following the input of ionizing radiations to observe their buildup, an ionizing pulse width of around a picosecond and an equally fast detection system need to be developed. These are short intervals in the present state of the art of linac and detection systems, but they are not impossible and their development should yield a variety of research projects along the way. The intended course for the linac in this development is to construct a new linac injection system capable of producing a pulse width which will be continuously variable from the existing maximum of $7.5 \mu\text{sec}$ down to the subnanosecond region. The Linac can then be used to investigate the short-lived radicals within this interval, while at the same time working toward the apparent goal of 1 picosecond (10^{-12}).

Preliminary work on the new injection system has already been started as a part of the linac development program, and a new gun structure with a demonstrated rise or fall time of 100 picosec (10^{-10}) has been developed. The intent now is to build a system utilizing this fast gun in combination with a velocity-modulating cavity and an accelerating cavity to produce a tightly bunched electron beam which then be injected through the linac's accelerating guide. The calculations for this system predict that the electrons will arrive at the exit end of the linac bunched to an axial spread of about 10^{-4} meter. This bunch length would produce a pulse-length at the target of $10^{-4}/3 \times 10^8$, or about 3×10^{-13} . Thus, the inherent capability of this system would allow the bunch length to spread, because of engineering problems by as much as an order and still be short enough for observing radical buildups.

The absorbed dose that will be generated by these pulses can be approximated in this way:

Each cm length of travel through a solution will absorb about 2 MeV from an electron beam in the energy range we are con-

sidering. Therefore, within reasonable limits, the energy deposited along the path of the electron beam will be a function of the current and of the diameter of the beam. The new linac system produce a spot size of about 4 mm^2 , and will have a pulse current of 175 mA. The energy deposition and absorbed dose along the exposure path for a 1- μsec

$$\frac{(2 \times 10^6 \text{ volts/cm})(0.75 \text{ A})(10^7 \text{ ergs/joule})(10^{-6} \text{ sec})}{0.04 \text{ cm}^2}$$

or $8.2 \times 10^7 \text{ ergs/cm}^3$.

In terms of absorbed dose this is 8.2×10^5 rads. This is more than adequate for generating a sufficient radical density to be observed.

For a 1-nsec pulse (10^{-9} sec), the absorbed dose will be

$$(8.2 \times 10^5) (10^{-3}) \approx 820 \text{ rads.}$$

This is still adequate for most radical species, since Dr. Hart of Argonne typically works with 1000-rad pulses and, with a little refinement, could get along with a third of that dose.

For the pulse widths less than 1 nsec the absorbed dose will continue to decrease with pulse width down to a pulse of 0.175 nsec. For pulses shorter than this width, 0.175-nsec pulse and bunch it in the direction of travel to produce the shorter pulses at the target. Therefore, the smallest absorbed dose would be

$$(820)(0.175) \approx 145 \text{ rads.}$$

This small dose is on the borderline of usefulness for most species. However, it can be increased in the following ways.

First, the peak current limitation of 175 mA results from the characteristics of the existing 45-in. accelerating guide. By replacing this guide with the new 120-in. accelerating guide already owned by the linac, the peak current could be raised to 300 mA. This would increase the dose at all pulse widths by $300/175$ or 1.7. The minimum dose would then become $(1.7)(145) \approx 250$ rads.

Second, the effects that cause a peak current limitation in an accelerating guide will not act as a limit on a beam pulse that travels through the guide on a single wave train. Since all pulse widths less than 0.175 nsec travel on a single wave train, the peak current of these pulses will be limited only by space charge effects, gun structure, and

available energy. Of these three, space-charge debunching appears to be the only serious problem. The gain in peak current allowed by these new constraints has yet to be determined, but an increase by at least a factor of two seems reasonable, and possibly a factor of 10 can be achieved.

Therefore, if the new accelerating guide were used, it appears that the minimum dose would be at least 500 rads. This is a usable dose for most radical species.

In comparing this proposed linac system with the new Argonne system, one finds that at the 10-nsec minimum pulse length for the Argonne machine the absorbed doses for the two systems are

Berkeley, 8 200 rads (16 200 rads with the new
accelerating guide);

Argonne, 10 000 rads.

In absorbed dose along the beam path, the two machines are about equal. However, Argonne's machine exposes a 1-cm² path while the Berkeley machine will expose only a 0.04-cm² path for the same dose. This will impose some hardship in cell design for pulse radiolysis systems, but for most applications this will be only a handicap and not a deterrent.

The first detection system will be based on the Argonne setup. This consists of a sample cell, a xenon light source, an old-style 1P28 photomultiplier, a fast scope, a monochromator, and a lens system. This combination has a demonstrated capability in the nanosecond region, and its simplicity and low cost make it an attractive initial system.

The electron linac's natural capability in pulse-radiolysis research should be developed. This is a growing area of research and one the Berkeley laboratories should participate in.

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