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PHYSICS DIVISION SEMIANNUAL REPORT

November 1964 through April 1965

Berkeley, California

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GENERAL PHYSICS RESEARCH

PHYSICS RESEARCH

Luis W. Alvarez in charge

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RESEARCH WITH BUBBLE CHAMBERS

Associated Production Experiment (72-Inch Chamber)

Strange-Particle Production by π^-p and π^+p

The study of the reactions $\pi^- + p \rightarrow \Lambda + K^0$, $\pi^- + p \rightarrow \Sigma^- + K^+$, and $\pi^- + p \rightarrow \Sigma^0 + K^0$ at incident π^- momentum of 1170 MeV/c has been continued. We made use of events $\pi^- + p \rightarrow \Sigma^0 + K^0$ followed only by a Λ decay to gain information about the angular distribution and polarization of the Σ^0. A theorem[1] (upon which an attempt to predict Σ^- polarization from Σ^-, Σ^0, Σ^+ angular distributions and Σ^0, Σ^+ polarization measurements was based) was found to contain an error, predicting more significant Σ^- polarizations than can actually be obtained. A study of n-p scatterings produced by the neutrons in Σ^- and Σ^+ decay, combined with the prediction of Σ^- polarization and measured Σ^+ polarization,[2] should yield the decay parameter γ for the Σ^- and Σ^+ decays. However, the revision of the Σ^+ polarization prediction affects the statistical precision in measurement of γ from Σ^- decays.

All together, 110 000 pictures of π^- incident on hydrogen at momenta from 910 MeV/c to 1000 MeV/c were taken to study phenomena in the Λ-K^0 system in this region. Analysis is now in progress. (JCD, JAA, FSC)

Eta Production

We are concluding our analysis using the 113 etas from the reaction $\pi^+p \rightarrow \pi^+p\eta$ at 1170 MeV/c, 41 η's from the same reaction at

1050 MeV/c, and 64 η's from the reaction $\pi^- p \to \pi^- p \eta$ at 1170 MeV/c. The production Dalitz plots are being analyzed in order to determine the percentage of $N^*(1238) \to \pi^{\pm} p$ and $N^{**}(1512) \to \eta p$. Assuming no $N^{**}(1512)$, we can explain the production process in terms of s- and p-wave production of the η, and s- and p-wave decay of the (π-p) system. A high percentage of N^* production is found in all three samples. $I = 1/2$ is important in the π^- data. Total cross sections are being calculated. (RAG, FSC)

Eta Decay, $\eta \to \pi^+ \pi^- \pi^0$

We have completed our analysis of the π^0 energy spectrum in $\eta \to \pi^+ \pi^- \pi^0$. Although many theories fit this spectrum about equally well, only one (which employs an s-wave dipion resonant amplitude mixed with a nonresonant amplitude) gives good values for the branching ratio $(\eta \to \pi^0 \pi^0 \pi^0)/(\eta \to \pi^+ \pi^- \pi^0)$, as well as fitting the energy spectra and branching ratios in the decays $K^+ \to \pi^+ \pi^0 \pi^0$, $K^+ \to \pi^+ \pi^+ \pi^-$, and $K_2^0 \to \pi^+ \pi^- \pi^0$. We have also fitted the dipion mass spectrum in K_{e4} decays, and find it consistent with all the above.

We are now looking at the possible "plus-minus" asymmetry in the eta Dalitz plot, suggested by Friedberg, Lee, and Schwartz in an attempt to explain the $K_2^0 \to 2\pi$ decays. (LRP, FSC)

Eta Decay, $\eta \to \pi^+ \pi^- \gamma$

Our sample of 47 possible events of this type is being analyzed in an attempt to clean up the sample and to find possible biases that our selection criteria might have on the γ-ray spectrum. The analysis is complicated because:

(a) The separation from events with no missing neutrals must be made on the basis of χ^2 criteria. Thus Monte Carlo control experiments must be performed.

(b) There appear to be γ rays in our sample that come from some source (unknown) other than etas. (LSP, FSC)

K_2^0, K_1^0 Mass Difference

In order to obtain consistent results between our two experiments, of which one gives the magnitude of the mass difference ($|m_2 - m_1| < 1 \times 10^{+10}$ sec^{-1}) and the other gives the magnitude and sign ($m_2 - m_1 > 1 \times 10^{+10}$ sec^{-1}), theories[3] that involve the mixing of the K_1 and K_2 and the effect of external magnetic fields on their relative phase have been tested. For the same purpose, we have attempted a phase-shift analysis for our 107 neutral K-meson interactions in hydrogen as well as one for charged K-meson interactions.[4] (BBC, FSC, GM)

Leptonic Decays of Neutral K's

A sample of 38 leptonic K^0 decays has been obtained from the reaction $\pi^- p \to \Lambda K$ at a beam momentum $\approx$1 BeV/c. Associated production events in which only the Λ has been observed in previous analysis were reexamined. The direction of the K^0 line of flight has been calculated and a search conducted for possible leptonic decays along it. The resulting events are being used to test the $\Delta S/\Delta Q$ selection rule and to examine theories[5] about CP violation in K^0 decays. (RLG, FSC)

1. L. Michel, Nuovo Cimento 22, 203 (1961).
2. F. S. Crawford, F. Grard, and G. A. Smith, Phys. Rev. 128, 368 (1962).
3. R. Spitzer, Nucl. Phys. 47, 367 (1963); F. S. Crawford, Alvarez Memo NFD No. 498.
4. M. B. Watson, M. Ferro-Luzzi, and R. D. Tripp, Phys. Rev. 131, 2248 (1963); V. J. Stenger, W. E. Slater, D. H. Stork, H. K. Ticho, G. Goldhaber, and S. Goldhaber, Phys. Rev. 134, B1111 (1964).
5. See, e.g., R. G. Sachs, Phys. Rev. Letters 13, 268 (1964).

K72 Experiment (72-Inch Bubble Chamber)

The K72 experiment consists of an exposure of the 72-inch hydrogen bubble chamber to a beam of K^- mesons. The incident momentum was varied in 100-MeV/c steps from 1.0 to 1.7 BeV/c. The exposure, totaling 14 000 events per mb, was taken between October 1961 and June 1962. A large number of results have been published. The remaining projects include some which have required detailed analysis and others which have received attention only recently after conclusion of more obvious projects.

Properties of Ξ Production and Decay

The reactions $K^- + p \to \Xi + K(+\pi)$ have been analyzed from threshold to 1.7 BeV/c. The full sample contains 1004 Ξ^- and 167 Ξ^0 events. The analysis of the spin of the Ξ yields confidence levels of approximately 0.02 and 0.40 for hypotheses 3/2 and 1/2, respectively. Upper limits have been set on the $\Delta S = 1$ leptonic decay modes of the Ξ^- and Ξ^0. Our results have been compared with predictions of the $|\Delta I| = 1/2$ rule and of SU_3; no

significant violation of these predictions was found. (JPB, PE, JRH, DM, JBS, FTS, MLS, PW)

Investigation of $K^-p \to \Lambda\omega$

The decay of ω mesons into various channels has been studied according to the reaction $K^-p \to \Lambda\omega$. If we set the rate of ω decay into $\pi^+\pi^-\pi^0$ to be $\Gamma(\pi^+\pi^-\pi^0) = 1$, then $\Gamma(\text{neutrals}) = 0.96 \pm 0.016$, $\Gamma(\pi^+\pi^-\gamma) < 0.08$, and $\Gamma[(\eta \to \pi^+\pi^-\pi^0)\gamma] < 0.006$. The $\pi^+\pi^-$ decay mode has been treated by using amplitudes rather than rates. The result is $[\Gamma(\pi^+\pi^-)]^{1/2} = 0.17 \pm 0.03$. Total cross section for $K^-p \to \Lambda\omega \to \Lambda\pi^+\pi^-\pi^0$ at 1.32, 1.42, 1.52, 1.60, and 1.69 BeV/c are 0.80 ± 0.06, 0.97 ± 0.08, 0.96 ± 0.05, 0.78 ± 0.05, and 1.01 ± 0.06 mb, respectively. Decay angular correlations have been expressed in terms of a density matrix. Study of the density matrices has indicated that no simple exchange model provides a full description of the process even when absorption is taken into account. (PE, SMF, DOH, JJM, JB-S, FTS, MLS, CGW)

K^-p Charge-Exchange Scattering

The charge-exchange reaction $K^- + p \to \bar{K}^0 + n$ has been studied at 1220, 1420, 1510, 1600, and 1700 MeV/c incident K^- momentum.[6] Of 30 000 VO-prong events, 3804 fit the reaction and satisfy other selection criteria imposed to minimize biases. The cross sections are, from low to high momentum, respectively, 2.94 ± 0.15, 1.98 ± 0.12, 1.91 ± 0.10, 2.02 ± 0.14, and 1.73 ± 0.10 mb. When fitted to a Legendre polynomial series, the angular distribution at 1220 MeV/c requires terms through P_6; at the other momenta, terms through P_7 are necessary and sufficient. The dominant qualitative feature of the distributions, as a function of increasing momentum, is the rapid decline of a sharp backward peak and the rise of a blunt forward peak. The backward peak is perhaps associated with the tail of the $Y^*(1815)$. The bluntness of the forward peak precludes its interpretation in terms of a simple ρ-exchange mechanism. (CGW, FTS, MLS)

The Reaction $K^- + p \to \Sigma^\pm + \pi^\mp + \pi^0$

The reaction $K^- + p \to \Sigma^\pm + \pi^\mp + \pi^0$ has been investigated for K^- momenta between 1.2 and 1.7 BeV/c. The cross section for this reaction changes very little throughout the momentum region investigated here, from 0.8 mb up to 1.1 mb. The rates of production of the $Y_0^*(1405)$ and $Y_0^*(1520)$ remain constant between 1.2 and 1.7 BeV/c, $\sigma[Y_0^*(1405)] \approx 150$ μb, $\sigma[Y_0^*(1520)] \approx 200$ μb, while $\sigma[Y_1^*(1660)]$ shows a statistically significant enhancement at 1.4 BeV/c [$\delta \sim 250$ μb]. The $Y_1^*(1765)$ does not appear at any of the momenta studied here; hence its branching ratio for this decay mode is less than 10%. (AB-G, MHA, AHR)

Lambda Interactions in Hydrogen

A study of $\Lambda + p$ interactions with initial Λ momenta from 0.4 to 1.5 BeV/c in the laboratory system is near completion. About 150 Λ interactions have been gleaned from a total sample of 500 neutral strange-particle interactions. The analysis of the elastic Λ scattering is essentially complete; 75 of these events fit unambiguously. The final states $\Lambda + N + \pi$, $\Sigma + N$, and $\Sigma + N + \pi$ often yield ambiguous results. The constraints implied by charge independence are being used to help determine the cross sections for these reactions. (MHA, JRH, PW)

The Reaction $K^-p \to \Sigma^\pm \pi^\mp \pi^+ \pi^-$

See report of K63 experiment.

6. Preliminary results at 1220 MeV/c are given in M. Ferro-Luzzi, F.T. Solmitz, and M.L. Stevenson, in 1962 Intern. Conf. on High Energy Physics, p. 376.

K63 Experiment (72-Inch Bubble Chamber)

The K63 exposure of the 72-inch hydrogen bubble chamber to a K^- beam has been completed, with approximately 1 300 000 pictures, and about 7 K^- per picture. The K^- beam momentum ranged from 1.7 to 2.7 BeV/c for the liquid hydrogen exposures. Deuterium exposures were at 2.1 and 2.65 BeV/c, and a lead plate exposure at 2.1 BeV/c. About 150 000 events have been measured to date, and a like number remains to be measured.

Properties of $\Xi^*(1817)$

Among the general group of baryon resonances, the strangeness-2 states have probably received the least experimental scrutiny because of low production cross sections and the subsequent difficulty in collecting statistically significant samples of these states. In a systematic analysis of all reactions involving $B = +1$, $S = -2$ particle configurations, we have identified the presence of a state with these quantum numbers at a mass of 1817 MeV. We have found the relative decay rates of $\Xi^*(1817)$ to be:

$$(\Lambda\bar{K}^0)^{0,-} : (\Xi\pi)^{0,-} : [\Xi^*(1530)\pi]^{0,-} : (\Xi\pi\pi)$$
$$:: 11.4 \pm 2.6 : 10.8 \pm 2.7 : 3.0 \pm 1.5 : > 1.1 \text{ (all in } \mu\text{b)}.$$

The spin has been found to be greater than 1/2, with spin 3/2 indicated.[7] (GAS, JL, JBS, JJM)

Analysis of $K^- p \to \bar{K}^0 p \pi^-$ and $K^- p \to p \bar{K}^0 \pi^0 \pi^-$

In the 2.45-BeV/c exposure of the K63 run we have identified 913 events of the type $K^- p \to p \bar{K}^0 \pi^-$ and 500 events of the type $K^- p \to p \bar{K}^0 \pi^0 \pi^-$. A maximum-likelihood fit to the three-body final state showed 58% of the events were going through the pseudo two-body final state

$$K^- p \to K^{*-} p. \quad (1)$$

A fit to the four-body final state showed 48% of the events were going through the pseudo two-body final state

$$K^- p \to K^{*-} N^{*+} \quad (2)$$

Differential cross sections for Reactions (1) and (2) as well as spin density matrix elements for the K^{*-} in Reactions (1) and (2) and the N^{*+} in Reaction (2) have been calculated. The differential cross section in both reactions is very sharply forward peaked, suggesting a peripheral mechanism. Maximum-likelihood fits are being made to determine the free parameters of two formalisms: one meson exchange with energy-independent form factors and one meson exchange with absorption. Programs have been coded to do a maximum-likelihood fit simultaneously to the production and decay angular distributions of the resonances for both models.

The general FORTRAN programs which are used in the maximum-likelihood analysis in computing the resonance production cross sections are being modified to allow variation of masses and widths of the resonances.

The density matrix elements were calculated with the help of Peter Schlein's moment program. (JHF, RRR, DMS)

Further Study of the 958-MeV Meson Resonance

Collection and analysis of data on the X^0 meson is continuing. To the present, some 360 events of the type $K^- + p \to \Lambda + X^0$, $\Lambda \to p + \pi^-$, $X^0 \to \eta + \pi^+ + \pi^-$ (280 events), or $X^0 \to \rho^0 + \gamma$ (80 events) have been observed. The internal correlations of the decay still favor the quantum number $I(J^{PG}) = 0(0^{-+})$, although a J^P of 2^- cannot be ruled out. The production process is being investigated for confirmation of these quantum number assignments. Production is quite sharply peaked in the forward direction ($\cos\theta > 0.7$ for $\approx 90\%$ of the events), which is the result predicted for a spin-0 X^0 meson, if a peripheral process involving K^* exchange is invoked. A study of reactions in deuterium, to be done shortly, will test the I-spin hypothesis; a search for charged resonant states in the reactions $K^- + p \to \Sigma^\pm + \pi^\mp + \pi^+ + \pi^- +$ neutrals has yielded no enhancement in the X^0 mass band, which is consistent with the I = 0 assignment. (AR)

The Reaction $K^- + p \to \Sigma^\pm + \pi^\mp + \pi^+ + \pi^-$

The production of $Y^*(1660)$ followed by the decay $Y^*(1660) \to Y^*(1405) + \pi$ has been observed in the reactions $K^- + p \to \Sigma^\pm + \pi^\mp + \pi^+ + \pi^-$.[8] Further investigation of this phenomenon has yielded a determination of parity = -1 for the $Y^*(1660)$, assuming $Y^*(1405)$ to be $1/2^-$. This research is being conducted with data from both the K72 and K63 experiments. (MHA, PE, AB-G, RRR, DMS, FS)

Analysis of Ξ^- Decay

The decay $\Xi^- \to \Lambda + \pi^-$ of Ξ^- hyperons produced in the reactions

$K^- + p \to \Xi^- + K^+$	(329 events)
$K^- + p \to \Xi^- + K^+ + \pi^0$	(608 events)
$K^- + p \to \Xi^- + K^+ + \pi^+ + \pi^-$	(77 events)
$K^- + p \to \Xi^- + K^+ +$ neutrals	(65 events)

at incident K^- momenta of 2.45 to 2.7 BeV/c has been studied. With the use of the 329-event $\Xi^- K^+$ sample (in which the Ξ^- are observed to be strongly polarized along the production normal) the Ξ^- decay parameters were determined, through application of both a moment-projection method and a maximum-likelihood method. Both methods use the language of irreducible tensors [see Byers and Fenster, Phys. Rev. Letters 11, 52 (1963)] to describe the initial Ξ spin state. No discrimination between spin 1/2 and spin 3/2 was obtained. With the Ξ^- spin taken to be 1/2 (on the basis of other data), and with $a_\Lambda = 0.62$, a maximum-likelihood analysis yields values for the Ξ^- decay parameters

$$a_{\Xi^-} = \frac{2\mathrm{Re}\, S^* P}{|S|^2 + |P|^2} = -0.24 \pm 0.12 ,$$

$$\Phi_{\Xi^-} = \tan^{-1} \frac{2\mathrm{Jm}\, S^* P}{|S|^2 - |P|^2} = 2.28 \pm 0.35 ,$$

where s and p denote amplitudes for s-wave and p-wave decay.[9]

Analysis of an additional sample of 235 events at 2.1 BeV/c indicates an average Ξ^- polarization of only 0.31 ± 0.14, compared with about 0.75 at 1.7 BeV/c and about 0.9 at 2.45 BeV/c. The average polarization of the 750 three-body and four-body events is likewise small. Combining estimates of a_{Ξ^-} from all available K-63 Ξ^- events ($a_{\Xi^-} = -0.24 \pm 0.12$, -0.57 ± 0.16 and -0.42 ± 0.10 for the 329-, 235-, and 750-event samples, respectively) yields a best value $a_{\Xi^-} = -0.39 \pm 0.07$. (DM, JBS)

Analysis of Ξ^0 Decay

Some 230 events have been unambiguously identified as examples of the reaction

$$K^- p \rightarrow \Xi^0 + K^+ + \pi^-; \quad \Xi^0 \rightarrow \Lambda + \pi^0$$

produced at incident K^- momenta between 2.45 and 2.7 BeV/c. With the spin of the Ξ^0 taken as 1/2, a maximum-likelihood analysis on this sample yields $\alpha_{\Xi^0} = -0.43 \pm 0.18$. Stringent selection criteria have been applied to exclude non-Ξ^0 events from the sample: from an analysis of similar events produced by a π^- beam at comparable momenta, the background in the 230-event sample due to π^--beam contamination is estimated to be fewer than 10 events. A combined sample of 440 unambiguous Ξ^0 events, including 32 events fitting $K^- + p \rightarrow K^0 + \Xi^0$ and 19 events fitting $K^- + p \rightarrow \Xi^0 + K^0 + \pi^+ + \pi^-$, as well as 159 unambiguous $\Xi^0 K^0$ and $\Xi^0 K^+ \pi^+$ events from K-72 data, yields a best value $\alpha_{\Xi^0} = -0.30 \pm 0.13$. This value is consistent with the requirement of the $\Delta I = 1/2$ rule that $\alpha_{\Xi^0} = \alpha_{\Xi^-}$.

A preliminary examination has been made of 348 Ξ^0 events in two- and three-body final states in data at K^- momentum of 2.1 BeV/c. Polarization of the Ξ^0 is found low in both classes of events. The value of α_{Ξ^0} is close to -0.60 (which brings the α_{Ξ^0} estimate even closer to the α_{Ξ^-} value). (DM, JBS)

$\Xi^*(1530)$

Analysis has been made of 124 $\Xi^* K \pi$ final states produced by $K^- p$ interactions at 2.45 to 2.70 BeV/c. Because of the dependence of polarization on production angle, the events were separated into those with Ξ^*'s going forward and those with Ξ^*'s going backward in the c.m. Confidence levels for the various $\Xi^*(1530)$ spin and parity hypotheses:

Forward events	Backward events
$J = 1/2$: 10^{-4}	$J = 1/2$: 10^{-4}
$J = 3/2$: 0.50	$J = 3/2$: 0.25
$P_{3/2}$: 0.17	$P_{3/2}$: 0.80
$D_{3/2}$: 0.30	$D_{3/2}$: 10^{-3}

A combination of χ^2 results for the forward and backward samples yielded a total parity χ^2 of 8.2 for P 3/2 and of 23.4 for $D_{3/2}$ (with 8 degrees of freedom), and thus a confidence level of 0.003 for the latter. (JBS, GAS, JL)

Decay Modes of the ϕ Meson

The reactions $K^- p \rightarrow \Lambda K^+ K^-$ and $K^- p \rightarrow \Lambda K_2^0 K_1^0$ have been analyzed at 2.45 to 2.70 BeV/c, and 400 events of the type $K^- p \rightarrow \Lambda \phi$ were found. In addition, a study of the reaction $K^- p \rightarrow \Lambda \pi^+ \pi^0 \pi^-$ has yielded information on the decay mode $\phi \rightarrow \rho \pi$. This decay mode is inhibited because the ϕ and ω result from the mixing of two "bare" particles, and its rate is determined by the extent of the mixing. SU3 predicts that if ω decay via $\pi^0 \gamma$, ϕ may have a substantial decay rate into $\eta\gamma$. Therefore, we have investigated the reaction $K^- p \rightarrow \Lambda \pi^+ \pi^-$ (+ neutrals) in order to set an upper limit for this decay mode. Preliminary results for the decay branching ratios are

$$\begin{aligned} \phi \rightarrow K^+ K^- &= 0.46 \pm 0.04 , \\ K_1^0 K_2^0 &= 0.36 \pm 0.04 , \\ \rho \cdot \pi &= 0.18 \pm 0.08 , \\ \eta\gamma &= 0.0 \pm 0.10 . \end{aligned}$$

The cross section for the reaction $K^- p \rightarrow \Lambda \phi$ is 53 ± 5 μb. (JL, GAS)

Charge Exchange and $\Lambda^0 + \pi^0$ Production in $K^- p$ Interactions near 2.5 BeV/c

The reactions $K^- p \rightarrow \bar{K}^0 n$ and $K^- p \rightarrow \Lambda^0 \pi^0$ are being studied. The cross section $\sigma(\bar{K}^0 n)$ decreases from 620 μb at 2.46 BeV/c to 400 μb at 2.70 BeV/c, while $\sigma(\Lambda^0 \pi^0)$ declines from ≈ 300 to ≈ 150 μb over the same interval. The production angular distributions for $\bar{K}^0$ have been fitted to a Legendre-polynomial expansion that requires only sixth-order terms to fit the data at 2.64 BeV/c. The pure I = 1 channel $\Lambda^0 \pi^0$ is being analyzed in the same way, and in correlation with the Λ^0 polarization. (FS, AB-G, RDT)

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7. Gerald A. Smith, J. S. Lindsey, J. B. Shafer, and J. J. Murray, Phys. Rev. Letters 14. 25 (1965).
8. M. H. Alston, A. Barbaro-Galtieri, Arthur H. Rosenfeld, and Stanley J. Wojcicki, Phys. Rev. 134, 1289B (1964); P. Eberhard, et al., Phys. Rev. Letters 14, 466 (1964).
9. The methods of analysis and treatment of a portion of the above data are discussed by Janice Button-Shafer and Deane W. Merrill in Spin and Decay Parameters of the Ξ^-, UCRL-11884 (Jan. 1965).

π63 Experiment (72-Inch Bubble Chamber)

The $K\pi$ Resonance Near 1400 MeV

The analysis of $\Lambda \pi^- K^+$ and $\Sigma^0 \pi^- K^+$ final states at 3.9 and 4.2 BeV/c has substantiated the existence of a $K\pi$ resonance near 1400 MeV,[10] reported by the British Collaboration Group.[11] The lack of analogous peaks in the $\Lambda \pi^0 K^0$ and $\Sigma^+ \pi^- K^0$ final states leads to the assignment of 1/2 for the I-spin. The spin analysis yields some additional evidence for the $J^P = 2^+$ assignment suggested by British data. (LMH, SUC, OID, RIH, JK, DHM)

Resonance Production in N K $\bar{K}$ π Final States

A study of the mass spectra of K $\bar{K}$ π systems has also given interesting new results: While the charged K $\bar{K}$ π combinations follow phase-space predictions, the neutral ones show two peaks. One of them corresponds to the E meson (1425 MeV), while the other one (the name D is proposed) has not been observed before. The D meson has a mass of 1285 ± 10 MeV, and width of 35 ± 10 MeV and I spin = 0. Angular correlations suggest the J^{PG} assignment of 1^{++}. The data also establish I = 0 for the E meson. (DHM, SUC, OID, LMH, RIH, JK, WK)

Production Mechanism for Σ^0 K^{*0} and Λ K^{*0} Final States

Elements of the density matrix for K^* production were determined. The results are consistent with peripheral production, and indicate that K^* exchange is more important than K exchange in the production process. (LMH, DHM)

Investigation of A_1 Production in π^- d Interaction

The reactions

$$\pi^- n \rightarrow \pi^- \rho^- p , \qquad (1)$$

$$\pi^- n \rightarrow \pi^- \rho^0 n \qquad (2)$$

were studied to gain further information about the A_1. The results show the A_1 being produced in Reaction (2), but not in Reaction (1). This leads to the conclusion that the A_1 is an I spin = 1 state and is not produced by the Peierls mechanism. (LS, OID, DHM)

Production and Decay of the ρ Meson

An analysis of the ρ-meson and π-π scattering has been undertaken, making full use of the Gottfried and Jackson absorption model but in the Huff linear momentum representation.[12] A calculation of the density matrix elements at various π-π energies is in progress from which it is hoped the phase-shift dependence will become explicit. There is also some evidence for the 2π decay of the ω; otherwise there is little or no evidence for any other enhancements in the ρ region--charged or neutral. (LDJ, DHM)

10. Lyndon M. Hardy, Suh Urk Chung, Orin I. Dahl, Richard I. Hess, Janos Kirz, and Donald H. Miller, Phys. Rev. Letters 14, 401 (1965).
11. H. Hague, D. Scotter, B. Musgrave, and others, Phys. Letters 14, 338 (1965).
12. See below under Special Projects: Absorption Effects.

K^- Beam at 435 MeV/c

Construction of a beam to be used with the 25-inch bubble chamber is under way. It is designed to transmit K^- mesons at 435 MeV/c. The beam uses a new type of separator which eliminates the need for two stages of particle separation, reducing the μ^- background and flux loss by decay. (JJM, ROB)

High-Energy Proton Experiment

At the end of this report period the new beam for the 72-inch bubble chamber is ready for operation. A collaboration with the Segrè-Chamberlain Group, with the Powell-Birge Group, and with groups at Stanford and UCLA, the experiment is designed to explore p-p interactions from 4 to 7 BeV/c as well as π^+p, π^-p, π^+d, and pd interactions at the highest energies available at the Bevatron. The plans call for more than 10^6 pictures to be taken during the coming year. (FS, GAS, ABW, MS, GG)

SPECIAL PROJECTS

Theoretical Predictions for the Production of Pseudoscalar and Vector Mesons

Density matrices and helicity amplitudes, as well as correlation coefficients for the decay angular distributions of the final particles, have been calculated in the most general case for the two reactions PF → P'F' and PF → VF', where P and P' are pseudoscalar bosons, V a vector boson, F a $1/2^+$ fermion, and F' a fermion of arbitrary spin and parity. These quantities have also been calculated specifically for any combination of spin (≤ 1) and parity exchanges in all three direct and crossed channels. For pseudoscalar plus vector exchange in particular,

programs have been written that numerically evaluate the density matrices and helicity amplitudes for both reactions. (RWH)

Absorption Effects

By absorption is meant the reduction of one inelastic cross section due to competition from other inelastic channels, this competition being estimated quantitatively from the differential elastic cross sections for the initial and final states. With various Born terms, used as starting points, expressions have been obtained from the partial-wave helicity amplitudes, with absorption effects included. These amplitudes are somewhat larger than Jackson, Gottfried, and Omnes obtained previously, especially when the absorption is large (i.e., absorbed amplitude greatly reduced), or when the real part of the elastic scattering amplitude is not negligible. Further, the amplitudes are only expected to be upper limits for high energies where some of the S-matrix eigenstates may have passed through more than one resonance. These amplitudes have also been obtained in a form that uses the Born terms and the differential elastic cross sections as functions of scattering angle, rather than requiring their decomposition into angular momentum states and a subsequent transformation of the absorbed amplitudes back into the desired angle-dependent forms. (RWH)

Computer Programs are being completed to numerically evaluate the absorbed helicity amplitudes for the processes PF→VF' and PF→R'F', assuming Born terms for pseudoscalar plus vector exchanges. (JHF, RWH)

Fermion Decay into Spin-3/2 Fermion Plus Spin-0 Boson

The decay of a fermion of arbitrary spin into an unstable spin-3/2 fermion plus a spinless boson is treated with density-matrix techniques. The formalism described is an extension of that developed by Byers and Fenster for the decay of a fermion into spin-1/2 and spin-0 particles. Decay distributions are completely described for three successive decay processes. Various tests for spin and parity of the parent fermion are suggested. (Abstract of paper to be published in Phys. Rev.) (JBS)

Spin Determination for Boson Resonances

A method of spin and parity determination has been worked out for boson resonances of spin S which decay into a spin-1 particle and a spin-0 particle. It is shown that the quantity S(S+1) can be given in terms of experimentally measurable averages. This affords a straightforward way of determining the spin uniquely. For the parity assignment, one finds that certain experimental averages are identically zero for one parity case and not the other. In addition, for the parity case in which two orbital angular momenta are allowed, decay parameters as well as multipole parameters for the spin-S particle can be determined. (Abstract of paper to be published in Phys. Rev.) (SUC)

DATA REDUCTION OPERATIONS

Personnel (Alvarez Scanning and Measuring Group

The group averaged 68.59 full-time equivalents over the period November 1, 1964, through April 31, 1965. The maximum reached was 73.00 in April. Approximately 85% of each of these figures represents effort; sick leave, vacation, holidays, etc., make up the remaining 15% in each case.

The average effort during this period was down 16% from the previous six months because (a) most of the holidays fall during this time of year, and (b) the previous six months included the summer when our part-time students work full time, increasing the effort then by about 30%.

Scanning

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

Scan and event type	Number of rolls
Experiment APE	
1. 1st general scan: 0 prong and V, 0 prong and 2 V's, scatterings, and leptons.	201
2. 2nd general scan: 0 prong and V, 0 prong and 2 V's, scatterings, and leptons.	111
3. Special scan: 2-prongs, zoons, efficiencies	10
K72 Experiment	
1. Λ Scatterings	463
2. Resolving ambiguities:	
event types 82 and 92	463
event types 84 and 94	463

Scan and event type	Number of rolls
event type 30	463
π63 Experiment	
1. Hyperons, 2nd scan	219
2. Deuterium scan	19
3. Four-prong scan	31
4. Two-prong scan	9
5. Cross-section scan	29
	Number of events
K63 Experiment	
1. 2.7 BeV/c, 2nd scan, all event types	7992
2. 2.63 BeV/c, 2nd scan, all event types	2881
3. Deuterium, 2.1- and 2.6-BeV/c, all event types, 1st and 2nd scans	42437
4. 2.1-BeV/c, 1st and 2nd scans, all event types	62053
5. 2.1-BeV/c, lead plate, 1st scan	20942
6. 1.7-BeV/c, 1st and 2nd scans, all event types	43429

Measuring

The following gives the production by machine:

Franckenstein measuring projector	Number of events measured	Number of hours of measuring
MPIIA	14576	2716
MPIIB	21711	2992
MPIIC	24431	2877
MPIID	28300	2981
Total (Franckensteins)	89018	11566
SMP measuring projector	**Number of events measured**	**Number of hours of measuring**
SMP 1	12665	1140
SMP 2	6416	732
SMP 4	5068	581
SMP 5	16747	1621
SMP 6	13762	1366
Total (SMP's*)	54658	5440
Grand Total	143676	17006

* The measuring rate for the SMP's averaged 10.0 events per measuring hours during the 6 months. Because of significant soft-ware improvements in the system, the rate, during the last 3 weeks of this period, went up 20%. Further increases are expected.

DATA REDUCTION DEVELOPMENT

SMP Development

General

The SMP system consists of five SMP's and one Executive typewriter operating on-line to an IMB 7040 computer. Operation during this report period has been satisfactory (see section on Data Reduction Operations for statistics on events measured). Several areas of program and hardware development of a minor nature are described below.

Program Development

Benjamin F. Abington, Richard W. Casey, Alice J. Lee, and Ronald R. Ross

1. The main SMP program was changed so it could be assembled under the FORTRAN IV IBSYS monitor system. This frees the system from its dependence on the 7094 computers using the 9 AP (modified) assembler.

2. During the change-over to IBSYS, parts of the program-handling interrupts from the SMP's and coordinate data input were replaced by a program called SMPXEC. This program was designed and implemented by John Munson for the University of Hawaii. This change did not constitute a major change in the operational aspects of the SMP's, but it has allowed a much more complete diagnosis of program and equipment failures.

3. The SMP program that intersects tracks to determine a vertex point (now called NTRSCT) has been changed and refined. The best track intersection is now used as a first approximation for a calculation that makes a weighted least-squares fit to tracks at a point and finds a final vertex by minimizing the χ^2. Refinements have been made in selecting tracks for intersecting, and the method of intersecting the tracks.

NTRSCT has been incorporated into the new SMP system and can be invoked by using Script 12 or 16. If track intersection fails a shadow wire is requested to measure the vertex.

Although NTRSCT is presently operational, it is felt that before the program is put into production further study should be made of its accuracy. Also, the program is being further refined to take full advantage of all track information, to minimize need for additional measurement.

4. The diagnostic program has been incorporated into the production version of the SMP program. Operators and maintenance men can now invoke the diagnostic program on any SMP while the rest of the system continues to operate normally. The "CRT" and the "straight-line fit" programs are available.

Hardware Development

Frank Neu and Maurilio Antuna, Jr.

Numerous changes were made to the SMP's to reduce maintenance, increase operator efficiency, and make the SMP operation more reliable. In addition, an Executive typewriter was installed for use by the programmers to type out errors detected by the computer during SMP operation. This has been a great benefit to the programmers in debugging their executive program.

Spiral Reader Development

Lester J. Lloyd, Gerald Lynch, Frank Hodgson, James Burkhart, Neven Travis, Jon Stedman, and James Baldridge

The Spiral Reader is now capable of reliable measurement at rates of about one single-vertex event per minute. A number of things have been done in the past 6 months to permit operation at this rate.

Stage positioning, film positioning, periscope, and view illumination have been put under the direct control of the PDP-4 computer. Film is now advanced automatically to the desired frame and the event to be measured is roughly positioned for the operator, with use of information provided to the computer on paper tape. The operator needs only to set the vertex of one event precisely at the center of the scan and occasionally measure an auxiliary point on short tracks with the stage. Fiducials are measured automatically under computer control and without the aid of the operator.

The computer programs for the PDP-4 have undergone extensive changes and improvement during this period. These improvements include stage- and film-positioning control programs, a new executive program, and programs to control each of the hardware functions. A number of maintenance programs have been written and put into operation. The filtering program POOH has undergone extensive improvement, and has been put into operation with the matching program which allows the measurement of unlabeled tracks and spurious tracks and determines with high reliability which tracks are associated with the measured event. Programs for the calibration of the optics of the Spiral Reader have been completed.

In conjunction with the experiment in progress now on the reader it has been determined that useful ionization information is available. Programs have been put into operation to use this information to resolve ambiguities in kinematics. Electronics is under development to improve the quality of the ionization information.

PROGRAMMING EFFORT

Personnel

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

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

Benjamin F. Abington II	James H. Burkhard	Orin I. Dahl
Margaret H. Alston	Richard W. Casey	Cecil T. Draper
James N. Baldridge	Lynn J. Champomier	Frank L. Hodgson
J. Peter Berge	Barbara J. Cottrell	Marjorie S. Hutchinson

Alfred D. Johnson
Nancy K. Joseph
Norman R. Larsen
Max Leavitt
Alice J. Lee
Thomas H. Oliver
Johnnie Shafer
Jon D. Stedman
Tomas R. Tonisson
Neven D. Travis

General Information

Most of the programs used by the Alvarez Physics Group for the analysis and handling of bubble chamber data have been described in previous semiannual reports. New analysis programs are being planned and written for use on the CDC 6600 computer. The improvements made to existing programs and new programs written in the past 6-month period are described below. For the purposes of review a brief description of these programs is given. Data from the measuring projectors are processed through PANAL to check for obvious errors and the format is standardized. PACKAGE does geometrical reconstruction of measured tracks and kinematical fitting of the events to various hypotheses via the two subprograms PANG and KICK. The WRING program reformats and compresses the PACKAGE output data for processing through physics analysis programs like DSTEXAM, which determines the interaction type, using the probabilities of the different hypotheses, and SUMX which makes histograms, plots, and tabulations of the results. The description of the processing for each event measured is kept by the library program LYRIC.

Data-Handling Programs

Scanning and Measuring Projector (SMP) Programs

(See Alvarez Data-Reduction Development.)

Spiral Reader Programs

(See Alvarez Data-Reduction Development.)

Library Programs

LYRIC II,[13] a new version of the library program LYRIC, is now in use. The major changes were to make more efficient use of computer time,[14] to increase the flexibility of the program to facilitate changes in processing procedures, and to give a more detailed history of the processing of an event. Planning is under way for conversion of LYRIC II to the CDC 6600 computer.

13. M. S. Hutchinson, LRL Alvarez Programming Group Memo P-112, July 1, 1964.
14. S. J. Penny, and M. Leavitt, LRL Alvarez Programming Group Memo P-120, April 13, 1965.

Data Conversion Programs

Two programs have been written which convert data formats in order to allow processing by Alvarez Group computer programs. One program converts data gathered at the University of Colorado from digitized microscopes, and the other converts data output from the Flying-Spot Digitizer program HAZE at LRL Berkeley.

Mass Store

Detailed study and evaluation of available mass storage devices was continued, with emphasis placed on integration of the device into the CDC 6600 system.[15]

15. M. H. Alston, and S. J. Penny, LRL Alvarez Programming Group Memo P-106, November 6, 1964.

Data Analysis Programs

Geometric Track Reconstruction Programs

The Three-View Geometrical Track-Reconstruction Program, TVGP,[16] has been completed and tested by processing a large sample of simulated track measurements as well as measurements of actual events from the SMP systems. Copies of the program have been sent to physics laboratories throughout the world. TVGP will be incorporated in the new analysis system being readied for used on the CDC 6600 computer.

The subprogram PANG of PACKAGE has been modified for use on the "Lead Plate" experiment, which was run in the past six months at the 72-inch bubble chamber.[17] This entailed restrictions on the geometrical path of reconstructed tracks to eliminate those which might have passed through the lead plates in the chamber.

16. A. D. Johnson, F. Solmitz, and T. B. Day, LRL Alvarez Programming Memo P-117, April 1, 1965.
17. G. Smith, and F. Solmitz, LRL Alvarez Group Memo 534, January 11, 1965.

Kinematics Fitting Programs

A new kinematics fitting program WAMPUM has been written. The method is similar to that used in FIT[18] at CERN. WAMPUM features single or multivertex fitting along with the capability to designate the parameters of a track as either well measured, badly measured, unmeasured, or fixed. This program will be incorporated in the new analysis system being planned for the CDC 6600 computer.

18. R. Bock, CERN 61-21, October 19, 1961.

Physics Analysis Programs

Work continued over the past six months on the conversion of programs DSTEXAM,[19] SUMX,[20] and DJINN[21] to the FORTRAN IV computer language that is to a large extent standard to IBM and CDC computers. Several programs were written for the statistical analysis of cascade hyperon two-body production.

19. O. Dahl, and G. Kalbfleisch, LRL Alvarez Programming Group Memo P-54, July 25, 1963.
20. Lynn J. Champomier, UCRL-11222, April 15, 1964.
21. J. Schwartz, and P. Bastien, LRL Alvarez Programming Group Memo P-58, Sept. 18, 1963.

BUBBLE CHAMBER OPERATION AND DEVELOPMENT

25-Inch Hydrogen Bubble Chamber

After the Trilling-Goldhaber and Powell-Birge K^+ and K^- experiments were concluded in mid-September, the 25-inch chamber was disassembled for repairs and modifications and reassembled.

The chamber was then moved into position for the Trilling-Goldhaber K_2 experiment, which started at the end of March. At this time, some 200 rolls of K_2 film (340 000 pictures) have been taken, with the chamber expanding twice per Bevatron pulse.

72-Inch Hydrogen Bubble Chamber

At the beginning of the report period, the 72-inch chamber was in operation in the K63 experiment with the lead plates installed. The chamber was shut down for a 2-week period in mid-November for the removal of the lead plates.

The K63 experiment concluded on the first of February. A total of 504 rolls of K63 film and 224 rolls of $\pi 63$ film was taken during the report period, for a total of 4.8×10^5 pictures.

The chamber was then moved to the high-energy proton beam, and the last week of April it started operation in this new position.

PHYSICS RESEARCH

Walter H. Barkas in charge

STRANGE-PARTICLE RESEARCH

K^+ Decays

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

τ and τ' Decay

The analysis of a sample of 376 τ'^+ decays in the energy region $T_{\pi+} = 0$ to 20 MeV and a sample of 3065 τ^+ decays has been completed.

Evidence is found for the presence of quadratic terms in the matrix elements of both decays. The data were used to test the "σ" resonance hypothesis of Brown and Singer [Phys. Rev. 133, B812 (1964)]. The resultant best-fit parameters are

τ'^+ decay: $M_\sigma = 345 \pm 5$, $\Gamma_\sigma = 86 \pm 8$;

τ^+ decay: $M_\sigma = 348 \pm 2$, $\Gamma_\sigma = 48 \pm 11$.

Since the widths differ by several standard deviations, it is improbable that the resonance hypothesis accurately describes τ and τ' decay. In addition to the difference in the best-fit widths, a χ^2 test on the τ^+ data gives only a 0.4% probability of fit for the resonance hypothesis.

K^+ Branching Ratios

Rescans have increased our sample of one-prong events from ≈ 660 to ≈ 700. All secondaries lie within acceptance cones defined on the basis of potential range in the stack. Approximately 660 of the 700 secondaries have now been followed.

In order to identify those events in which the secondary was lost, interacted in flight, or disappeared in flight, ionization measurements are being carried out. These measurements furnish unambiguous identifications for all but a very few events, and the program is near completion (≈ 10 events remain to be measured).

During the original scan, all stopping tracks that could have been K^+ were recorded, whether a secondary was seen or not. Those events with no observed secondary have been subjected to two successive rescans. The residual tracks (after three scans) are being followed back to determine whether or not they belong to the K^+ beam. Less than 5% of the residual tracks do belong to the incoming beam. Also, a partial rescan to evaluate efficiency for seeing apparent K^+ endings (irrespective of observation of a secondary) is being initiated. These measures should furnish decisive answers to the questions one must ask about efficiencies.

Mechanism of Hyperfragment Formation in K^- Capture

Jack W. Patrick

The study of a sample of 63 parent stars of hyperfragment production has been reanalyzed. It was deduced that a majority of the Λ's originate in Σ-conversion processes. The separation of K^- captures in C, N, or O from those in Ag or Br nuclei, done by Auger emission and length-of-secondary analysis, was critically examined. The new upper limit obtained was 20% or less for the fraction of the multinucleon absorptions taking place on heavy elements.

PION RESEARCH

Range Difference Between Negative and Positive Pions

Frances M. Smith

As pointed out in the preceding report, the uncertainty in the momentum of the pions passing through thin Au foils made the results of range-difference calculations ambiguous.

An experiment for the purpose of investigating the range difference further is being planned. An apparatus that will select the momentum to within a few percent will be used.

We plan to study the range difference in several different metals.

SPACE RESEARCH

Harry H. Heckman

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

A continued effort is being placed on the study of the flux, energy spectra and particle scale heights of the geomagnetically trapped protons in the South Atlantic anomaly. Four recoveries of emulsion detectors from low-altitude, polar-orbiting satellites were accomplished during this report period. The analysis of the particle data from these flights is in progress. Upon completion, these data will constitute part of a study of the temporal variations of the trapped radiation at low altitudes during the period of minimum solar activity, September 1962 through November, 1964.

The calculation of particle trajectories in the earth's magnetic field, using a 48-term expansion of the earth's field, have been used to evaluate the effective atmospheric densities and rates of energy loss per drift period for trapped 125 MeV protons. Atmospheres appropriate for periods of solar minimum and maximum are being used in the calculations. Atmospheric density scale heights for the particle's actual and guiding center trajectories have been obtained for a diurnally averaged atmosphere at solar minimum. (Atmosphere designated S = 100, Harris and Priester, NASA Report X-640-62-70.)

INSTRUMENTATION

TV Track-Analyzing Microscope

Harry H. Heckman and Henri Annoni

For the past several months we have been carrying out a program to evaluate the long-term stability and measuring capacilities of the TV track analyzer. We have found that all ionization parameters measured by this instrument are reproducible to an accuracy of 1 to 1.5% for periods up to 2 months. Detuning of the video circuit has occurred within this time by the precipitation of gray-white "powder" on high-voltage components. This precipitate appears to be associated with smoke particles or water vapor or both from the air conditioning system. Elimination of these possible factors has noticeably reduced the rate of collection of this deposit --thereby effecting an increased "on time" for the instrument.

We have completed a preliminary study on applying the TV analyzer to mass and charge measurements of stopping tracks in K.5 emulsion. A separation between tracks of charge one and charge two is found by area measurements for ranges $R \leq 300\ \mu$. Complete mass separation of $z = 1$ tracks--i.e., protons, deuterons and tritons--is obtained for residual ranges greater than 2.0 mm by integral gap-length measurements. For the particular 600-μ-thick emulsion sample used in these measurements, no depth corrections were required for depths greater than 50 μ from the top surface. Depth corrections to the measurements are necessary whenever emulsions have a large incident flux of particles or a high density of background grains, or are highly stained.

PHYSICS RESEARCH

Kenneth M. Crowe in charge

K DECAY

Kenneth M. Crowe, Tin Maung, Roy P. Haddock,* Juergen Pahl, Jerry Helland,* Michael Zeller,* Ned Dairiki, Robert M. Salter,* Phillip B. Beilin, and Robert L. Beck

A major Bevatron run was undertaken during the summer of 1964 and will continue into the summer of 1965. The objectives are as follows:

1. Measurement of the momentum spectra at the principle decay modes together with the branching ratios. This experiment was attempted in 1961 and results have been obtained. The new run will give as a byproduct these branching ratios and spectra, with considerably improved statistical significance.
2. Correlations of the leptonic decay mode for the decay modes

$$K \rightarrow \mu^+ + \pi^0 + \nu ,$$

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

The neutral π^0 will be detected in a spark chamber which will have an efficiency of $\approx 50\%$ for detecting both gammas. The correlation of the neutrino and lepton will be studied to improve the understanding of the process.

3. Measurement of muon polarization from $K_{\mu 3}$ stopping in a spark chamber which will be used to measure the polarization of the muons, and for a small sample both the π^0 and μ spin will be detected. An attempt will be made to follow the spin for varying momentum of the muon and correlated neutrino direction.
4. Measurement of the K_{e2} branching ratio. The K beam has been designed to provide enough stopped kaons for observation of the $K \rightarrow e + \nu$ mode $\approx 10^{-5}$ branching ratio. If the efficiency and necessary rejection can be made for backgrounds, the rate will be measured. A liquid hydrogen Cerenkov detector will be used to select K_{e2} from the $K_{\mu 2}$ that might confuse the events. The momentum resolution should be sufficient to separate the K_{e3} from the K_{e2}.

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* University of California, Los Angeles

MESIC x RAYS

David A. Jenkins and Robert E. Shafer

A series of experiments was begun to investigate mesic x-ray spectra with a solid-state germanium detector. Using pulse-height analysis techniques, one can record the complete mesic x-ray spectra in a short period of time with an energy resolution of approximately 7 keV. Earlier investigations of mesic x rays have not been very informative because of the poor energy resolution in the NaI crystal used for detection. However, the new solid-state germanium detector improves the energy resolution by a factor of ten, and it is now possible to do a more detailed analysis.

A preliminary run on the 184-inch cyclotron was conducted, and the apparatus is now being improved for a more thorough experiment this summer. We plan to investigate level shifts due to relativistic splitting, electron screening, vacuum polarization, and the nuclear interaction. We will also measure x-ray yields to determine the meson cascade process in the atom.

μ-DECAY SPECTRUM IN COPPER

Phillip Beilin

At the end of September 1964 an experiment measuring the electron decay spectra of free and bound muons in copper was concluded at the 184-inch cyclotron. Positive muons (or negative muons) were brought to rest in a 1/8-in. copper plate. The decay positrons (or electrons) were momentum-analyzed by an Elbek-type magnetic spectrometer. The theoretical μ^+ and μ^- decay spectra have been modified by the experimental resolution effects. The predicted numbers of decay electrons in each focal-plane counter have been compared with the numbers of electrons actually counted.

The numbers of predicted electrons were determined for a range of values for the Michel ρ parameter. The preliminary best value of the ρ parameter obtained for the positive spectrum lies considerably lower than the values, close to 0.75, recently reported by groups at Columbia and Chicago. At present the experimental error on the Michel parameter is being estimated, and in view of its critical importance the magnetic field

measurements of the spectrometer are being reexamined. This work should be concluded shortly.

π-π INTERACTION

Ned Dairiki and Tin Maung

We have studied the π-π scattering length from the reaction $\pi^- + p \rightarrow \pi^0 + \pi^0 + n$. In July, 1964, a cyclotron run was made on this reaction. The neutron velocity distribution was studied, using time-of-flight method triggering the event on a pair of γ rays which were confined to a small angle such that the single π^0 rate was excluded by kinematics. The results obtained were interpreted in terms of a π-π interaction in the form of an s-state attraction and phase space for the remaining states. The disagreement with these assumptions lead to introduction of another enhancement of the π-π state at higher energy similar to that found by Tripp et al. and by others. The existence of the π-π s-state interaction is consequently not uniquely determined unless the parameters of the 400-MeV π-π enhancement can be fixed.

Further running on this problem, with spark chambers for determining the four γ rays for the 2 π^0, is being considered for the fall of 1965.

PION MASS MEASUREMENT

Kenneth M. Crowe, Robert E. Shafer, and David A. Jenkins

The bent crystal was used to measure the 4F-3D π-mesic transition energies in calcium and titanium in order to obtain a better estimate of the π^- mass.[1] The measured transition energies (72.352 ± 0.009 keV for Ca and 87.652 ± 0.009 keV for Ti) yield a π^- mass of 139.580 ± 0.015 MeV, in agreement with the best indirect estimates, and an order of magnitude more precise than the previous best direct measurement. Combining this measurement with measurements of the μ mass and π-μ decay kinematics sets an upper limit of 2.1 MeV for the μ-neutrino mass.

1. R. E. Shafer, K. M. Crowe, and D. A. Jenkins, Phys. Rev. Letters 14, May 31 edition (1965).

THEORETICAL DIVISION

David L. Judd in charge

I. THEORY OF THE SCATTERING MATRIX

Relativistic extensions of the Faddeev equations for three-particle scattering have been investigated. They are obtained by starting from three-body Bethe-Salpeter equations, and applying to them the techniques introduced by Blankenbecler and Sugar[1] to keep only the contribution of Landau singularities associated with three-particle intermediate states. Consequently, solutions of the equations satisfy three-body unitarity exactly. The inhomogeneous term and kernel of the relativistic equations are determined only by the two-body scattering amplitudes, in which one of the particles is off the mass shell. When the two-body amplitudes are approximated by the contributions of bound states and resonances, the equations can be reduced to a set of integral equations in one variable. As a by-product of this study, the following results have been obtained: (a) a new proof of unitarity for the Lippmann-Schwinger and Faddeev equations; (b) a proof of the analytic properties of resonance form factors in the nonrelativistic theory; (c) a proof of the asymptotic behavior of these form factors. The development uses functional analysis techniques and is a rather general method for investigating the asymptotic behavior of solutions of Fredholm equations. (Victor A. Alessandrini* and Roland L. Omnes)

An attempt is being made to investigate in detail the properties of three-particle systems. The equations used are relativistic extensions, proposed by Alessandrini and Omnes,[2] of the Faddeev equations. They are made tractable by the assumption of a separable two-body off-shell amplitude.[3] The mathematical difficulties associated with the various singularities of the kernel of the equations have been fully analyzed and are handled with good accuracy. Preliminary results on the three-pion system with the quantum numbers of the omega meson are encouraging as to the possibility of explaining three-particle resonances. (Rodney E. Kreps† and Jean-Louis Basdevant‡)

In the model of Omnes and Alessandrini[4] for the three-body connected part of the scattering amplitude we have uncovered the following effect: all the peculiar singularities in the complex angular momentum plane found by these authors are not present if one makes their infinite mass finite. We are in fact able to extend the proof to any iterative order of the Neumann expansion of the Faddeev equations, thereby raising the hopeful possibility that the three-body connected part has only "normal" singularities in complex angular momentum; that is, those associated with three-body bound states and resonances. In the course of this work it was found necessary to investigate off-shell dispersion methods for the four-point function, specifically, spectral representations for the case of one off-shell line. It now seems likely that as a fruitful side result we shall be able to solve the long-standing Delbrück scattering problem; that is, the box diagram with two off-shell external lines. (Mark Sharefkin)

The assumptions necessary for a quantum mechanical theory of the strong interactions in which each particle is a bound state of other particles have been investigated. The structure of the space of states is shown to be determined entirely from the structure of the one-particle state. (Leonard Susskind**)

Work is now being done to derive a dynamical equation in a three-particle approximation for the masses, coupling constants, and scattering amplitudes of particles. The work differs from the bootstrap theory in that it does not deal with equations derived from the crossing symmetry and analyticity of the S matrix. Instead it uses an assumption that the n particle states are embedded in the space of states spanned by states with more than n particles. (Leonard Susskind**)

A set of partial-wave integral equations, similar to those of Rosenberg[5] but including spin, were reported in the preceding progress report. The properties of these equations and of their kernels are being studied in an attempt to do a numerical calculation of electron-deuteron scattering below the meson-production threshold and within the framework of nonrelativistic quantum mechanics. (Thomas R. Mongan)

Work has been continued on the attempt to treat three-particle systems in the same way as two-particle systems have previously been treated (the "N/D" method). It is essential that this problem be solved if correct calculations in elementary-particle physics are to be taken to higher approximations.

Although it does not appear feasible at the moment to include three-particle systems completely, one would hope to be able to take into account their most significant contributions, in which two of the particles are "resonant." The result of the investigation appears to be that three-particle systems are not more complicated in principle than two-particle systems, but the actual numerical work involved in treating them is much more lengthy. (Stanley Mandelstam)

A crossing-symmetric Regge representation for the invariant two-particle scattering amplitude has been constructed with simultaneously exhibits all Regge poles in the three channels. It is assumed that the amplitude satisfies the Mandelstam representation, and that the usual Mandelstam-Sommerfeld-Watson transform exists. To achieve explicit crossing symmetry it is found necessary to work with the Legendre function of the second kind. Except for neglecting the influence of possible angular momentum cuts, the representation is exact for all s, t, and u, with no restriction on the location of Regge poles. As an illustration of how it might be used in practice, the Chew-Jones formula for the amplitude of definite signature is derived in the strip approximation.[6] (Heinz J. Rothe)

A simple and straightforward method for identifying and removing the kinematic singularities of helicity amplitudes is constructed by using the Trueman-Wick crossing relations. A set of "amplitudes" which are free of all kinematic singularities is obtained for interactions for four particles of all spins and masses. (Ling-Lie Chau Wang)

Various questions concerning the calculation of partial-wave scattering amplitudes are being studied. Among these questions are the possibility of including inelastic effects within a one-channel N/D calculation, the form of the unphysical unitarity relation for partial-wave amplitudes, and the existence of conditions on the N function which will insure that the amplitude calculated from it will satisfy the necessary dispersion relation. (Jerome Finkelstein)

The unitarity equation for multiparticle processes is used to find the discontinuities of the scattering amplitude across its cuts. Discontinuity equations have been derived for the $3 \to 3$ and $4 \to 4$ amplitudes. Work that considers processes involving a larger number of particles is in progress. (Joseph Coster)

A study has been made (with M. L. Goldberger of Princeton University) of the role of observations in determining the decay law for unstable particles. An observation of confinement in space for a time longer than the free flight time across the volume of confinement serves to remove arbitrariness in the decay law. (Kenneth M. Watson)

A review of scattering theory has been written for the Dictionary of Physics. (Kenneth M. Watson)

A paper on accuracy of measurement (with M. L. Goldberger) has been written. (This concludes work mentioned in the preceding report.) (Kenneth M. Watson)

A technique for performing spectroscopic measurements is being developed in collaboration with H. W. Lewis of the University of California at Santa Barbara and M. L. Goldberger. (Kenneth M. Watson)

It is generally believed in analytic S-matrix theory that the $i\epsilon$ prescription[7] is a reflection of some causal principle.[8] An attempt is being made, using methods of functional analysis, to make explicit the connection between causality and the $i\epsilon$ prescription for normal singularities. The situation with respect to subenergies is believed to be understood, and work is in progress to include momentum transfers and cross energies in the theory. (Colston Chandler††)

A mechanism for resonance production is being developed, based on the iteration of unphysical scattering amplitudes. Such unphysical amplitudes represent inelastic intermediate states for real scattering processes. From this point of view it is felt that higher resonances (as in pion-nucleon scattering) are determined by the inelastic contribution to the intermediate state through unitarity. This would reflect the nearness of the right-hand unitarity singularities compared with the left-hand cross-channel singularities. Previous work in this direction has not led to physical enhancements, as the inelastic singularity considered was logarithmic and was too far removed from the physical region to affect it when physically observed widths were introduced. (Philip Farber)

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‡ CNRS-Paris, France, and NATO Fellow.
** National Research Council Fellow.
†† Danforth Fellow.

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II. PARTICLE PHYSICS

Various aspects of bootstrap dynamics within the framework of the analytic S matrix continue to be examined. The anomalous status of the $I = 0$, $J = 0$ $\pi\pi$ state is receiving particular attention, it being expected that the behavior here will throw important light on maximal analyticity of the second degree. A related question is the contribution of the Pomeranchuk Regge pole to low-energy dynamics. Our current bootstrap equations find this contribution to be negative, i.e., like a repulsion, and to produce effects of a novel character. The relation between Reggeized and elementary-particle potentials has been understood to a considerable extent, within the strip approximation. With a small difference ΔJ between the exchanged particle spin and the location of the associated trajectory in the crossed physical region, the elementary particle approximation is adequate. There is, however, generally an exponential damping factor $\approx e^{-c\Delta J}$, with $c \gtrsim 1$, which suppresses the influence of high spin exchanges. (Geoffrey F. Chew)

Some gaps in a previous argument[9] that a single particle cannot form a self-sustaining, or "bootstrap," system have been filled.[10] A method of treating the "potential" has been proposed which reconciles the Mandelstam iteration procedure with the Regge asymptotic behavior of the double spectral function, by making a subtraction of the s-wave discontinuity. This leads to a more general argument that unitarity and crossing symmetry put a very stringent limit on the magnitude of the coupling strength, and excludes the possibility of even producing the bound state corresponding to the particle. (P. D. B. Collins*)

A new form of the strip approximation devised by Chew[11] has been applied to the problem of "bootstrapping" a ρ trajectory in the π-π system. Even in the absence of other trajectories it is possible to obtain self-consistent trajectory and residue functions for a variety of strip widths in the range 150 to 300 m_π^2. A search is continuing for a more complete bootstrap containing the ρ, P, P', and possibly other trajectories. (P. D. B. Collins)

A computer program has been set up to make bootstrap calculations in the two coupled channels $\pi\pi$ and $K\bar{K}$, by the ND^{-1} method in the strip approximation. Preliminary results with elementary ρ and K exchange as the primary interaction are under investigation. (Shu-Yuan Chu)

The theoretical study of Regge dynamics in πN scattering initiated earlier has been completed. The kinematics of partial-wave amplitudes has been carefully analyzed and a basic N/D integral equation has been derived. The integral equation has been transformed to one of standard Fredholm type, and the inhomogeneous terms in the equation have been constructed in detail. The theory is now at a stage at which a numerical calculation could be attempted. The main output of such a calculation would be the positions and residues of the Regge poles in the πN channel. (John Stack)

Work is in progress to calculate the $\pi N \to \rho N$ cross section, considering Regge-pole exchange in the crossed channel. (Ling-Lie Chau Wang)

A calculation of the slope of the Regge trajectory near the Δ particle ($I = 3/2$, $J = 3/2$, π-N resonance) is being carried along in a simple model which has already proved to work very well. It assumes that the gross features of pion-nucleon interaction can be accounted for by the exchange of a nucleon in the crossed channel, considered as an elementary particle; and that Regge behavior can be simulated by a cutoff of dispersion integrals, which in turn can be used to adjust the mass of the Δ particle to its physical value. (Andres A. Garcia)

The reaction $\pi + p \to N^* + \rho \to p + \pi + \pi + \pi$ in a one-pion-exchange model was studied. By approximating the propagators of the two intermediate particles by delta functions, the invariant mass distribution of $p + \pi + \pi$ in the final state has been computed. The peaks in the $p + \pi + \pi$ mass distributions generated by

the above diagram were compared with experimental data obtained from $\pi + p \rightarrow p + \pi + \pi + \pi$ at the same energy. It is hoped that a general formalism can be achieved to compute all combinations of invariant mass distributions via an integration over phase space without having to resort to computer calculations using the FAKE program. (Ivan Kramer)

Nucleon-antinucleon potentials are being constructed. The real part of the potential is supposed to be given by single-meson exchanges, and is deduced from a corresponding N-N potential. The absorptive part is given by an imaginary Saxon-Woods potential, or by an ingoing wave boundary condition at some radius. Several good fits to the data have already been found. (Ronald A. Bryan† and Roger J. N. Phillips‡)

The role of Regge poles in high energy scattering has been considered in a phenomenological spirit. It has been shown that high-energy KN data contain further evidence for the R trajectory proposed by Pignotti.[12] It has also been shown that simple Regge pole models predict substantial real parts for the πp and pp forward scattering amplitudes, at energies of order 10 to 20 GeV, in agreement with experiment.[13] In a more extended analysis, it has been shown that πN, KN, and $\bar{K}N$ elastic scattering and charge-exchange data at high energy and small momentum transfer can be well fitted by a few Regge poles in the crossed channel.[14] Factorization constraints were included. The couplings of the Pomeranchuk and ρ Regge poles were found to satisfy SU_3 unitary symmetry. (Roger J. N. Phillips and William Rarita**)

Work is in progress on the semiphenomenological calculation of the π-π scattering length, with forward-direction elastic-scattering dispersion relations. The low-energy contributions to the integrals are being evaluated in terms of the available information on total pion-pion cross sections, while the high-energy contribution is calculated by use of the known expression for the amplitude at large energies and small momentum transfers given by the Regge pole hypothesis. The Regge pole parameters have been obtained from the data of Roger J. N. Phillips and William Rarita by use of the factorization theorem for the residues. (Heinz J. Rothe)

The $d_{3/2}$ meson-baryon resonances (gamma-octet resonances) are being studied on the basis of a multichannel Bethe-Salpeter equation in the unitary symmetry limit. The force mechanism studied consists of a box diagram which provides strongly attractive d-state forces corresponding to the octet channels. A reduction of the Bethe-Salpeter equation to a one-dimensional relativistic integral equation which incorporates two-body unitarity has been effected along the lines of the method of Blankenbecler and Sugar. A numerical solution of the equation is in progress. (Paul van der Merwe)

Calculation of the effects of the π-π s-wave interaction on the process $\gamma + p \rightarrow \gamma + p$ is now almost completed. Several surprising features seem to emerge:

(a) The sign required for the π^0 exchange term may be opposite to the sign predicted by the Goldberger-Treiman relations.

(b) The couplings of the η to $N\bar{N}$ and $\gamma\gamma$ may be several orders of magnitudes larger than the SU(3) values.

(c) It does not seem possible to find any π-π interaction whose effect is powerful enough to ensure agreement between theory and experiment in the Compton scattering process. An analysis is being carried out to examine the effects of higher-mass intermediate states, in particular those involving the $N^*_{13}(D_{3/2})$ and the possible $N^*_{11}(P_{1/2})$ nucleon isobars. (Elliott Leader)

The corrections to the Born term (in proton-proton scattering), as given by the Chew-Arndt, MacGregor-Arndt (j_0 even), and Scotti-Wong models, have been shown to be bounded above and below. The bounds follow from the mathematical forms of the approximation schemes, to all of which a certain theorem applies. A proof of this theorem has been carried out. The correction bounds are calculated for $^3P_1$, $^3P_2$, $^1D_2$, ϵ_2, $^3F_2$, $^3F_3$, $^3F_4$, $^1G_4$, and ϵ_4, for the range 0 to 300 MeV. The results are shown to explain why the apparently different models mentioned above all give similar Born terms after subtraction of the correction from the experimentally determined amplitude. These results are being prepared for publication. (Judith Binstock)

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** Physics Department, University of California, Berkeley, visiting scientist.

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III. PHYSICS OF THE NUCLEUS

A paper on the equilibrium shapes of rotating liquid masses if being prepared for publication in collaboration with Stanley Cohen of the Argonne National Laboratory and Franz Plasil of the Chemistry Division (W. J. Swiatecki)

Estimates of the reduction in the spontaneous fission half-life of a heavy nucleus were made in connection with the anomalously short-lived americium isomers discovered recently in the USSR. Certain refinements to the standard liquid-drop theory of nuclear fission are also being investigated, in particular the effect of a variable nuclear surface tension, depending on the local curvature of the nuclear surface. (W. J. Swiatecki)

Preliminary investigations are being made in connection with the hydrodynamics of the absorption of a heavy ion by a heavy nucleus. An analogue experiment carried out in Stanley G. Thompson's group in the Chemistry Division suggests an unexpected mechanism in which, under certain conditions, only part of an impinging heavy ion would be absorbed by the target nucleus. The process appears to be a sensitive function of the viscosity of the fluid, and might provide information on the viscosity of nuclear matter. (W. J. Swiatecki)

A new theory of nuclear masses and deformations has been developed. An exposition of this work is being prepared which describes in detail the way in which the effect of deformation on nuclear shell structure is taken into account. An accompanying table will list the mass, deformation, and other nuclear properties predicted by this theory. (William D. Myers)

IV. MANY-BODY AND ATOMIC PHYSICS

The λ transition in an interacting boson system is being investigated in a simple model defined by (a) the Born collision approximation, (b) a short-ranged potential, (c) the low-density limit. The Born collision approximation is the simplest "conserving" many-body approximation that includes collisional or "lifetime" effects. Explicit calculation of the real part of the self-energy at low momenta produces the $p^{3/2}$ spectrum of Patashinskii and Pokrovskii. The imaginary part of the self-energy at low energies varies linearly with the energy. Because of the $p^{3/2}$ spectrum, the three second-order partial derivatives of the Gibbs potential display logarithmic behavior. The model is being pursued further, with emphasis on quasi-particle operators and two-particle correlation functions. (Victor K. Wong and Andrew M. Sessler)

A phenomenological treatment of radiation quenching processes in low-density gases has been developed, including pressure effects on line shapes. The theory is valid only to first order in the density of gas particles. Presently, open diagram techniques are under investigation for application in transport theory contexts which will enable one to produce a precise formulation of the quenching problem and offer a convenient framework for the study of other phenomena relevant to resonance radiation absorption by low-density gases. (Bandel Bezzerides)

An approximation mode, variationally derived, describing symmetric resonant charge exchange wherein the initial and final channels are coupled exactly has been formulated for a system admitting an exact solution. Not unexpectedly, the numerical results for the high-energy case in which atomic wave functions are employed were much better than those from first-order approximations at intermediate energies, and rapidly converged to the latter at higher energies. (James Quong)

V. MISCELLANEOUS TOPICS

Calculation has been completed of the first correction term to the second adiabatic invariant ($\int p_{\parallel} ds$) of charged-particle motion in magnetic mirror fields. The expansion parameter ϵ is the ratio of the radius of gyration to the scale length of the field. After an extensive calculation, the following simple result has been found: the total correction is obtained by using the first invariant (magnetic moment) correct through order ϵ, and by

accounting for the change in the lowest order of the second invariant caused by guiding-center drift across field lines. (Theodore G. Northrop and Chuan She Liu)

Finite gyro-radius corrections to the phase velocity of waves in a uniform Vlasov plasma have been found from modified hydromagnetic equations.[15] Some of the finite gyro-radius terms have been omitted in previous work.[16, 17] The effect on the Alfvén wave instability[18] is obtained as a special case, and is found to be stabilizing unless the ion pressure is nearly isotropic and the electron pressure parallel to the magnetic field is large. (Alan Macmahon)

The well-known infrared divergences encountered with the radiative-correction calculations in quantum electrodynamics have been conventionally eliminated by summing the divergent cross sections over all possible final states consistent with experimental resolution.[19] We have shown instead that by a proper choice of initial and final states, the divergences can be canceled to all orders in the matrix element. These states are not the usual eigenstates of the photon number, and have a parameterization similar to that used by Glauber.[20] The condition for the cancellation of the divergences in some simple processes requires that the initial and final photon states belong to unitarily inequivalent representations of the canonical commutation rules. (Victor Chung)

The hypothesis is being investigated that the ultraviolet divergences in quantum field theory are closely connected with conformal invariance at extremely high energies. The reason is that a number of theories--e.g., quantum electrodynamics and pseudoscalar-pseudoscalar meson theory--are conformally invariant for vanishing rest masses, and a new class of solutions is connected with this invariance. These solutions have an essential singularity on the light cone; in order to regularize them one has to introduce a new class of test functions which vanish strongly on the light cone. Since the ultraviolet divergences have their origin in singularities on the light cone, it seems possible to treat them by means of this new class of test functions. First results are contained in a recent paper.[21] (Hans A. Kastrup*)

Work has been carried out in the area of "spin." The algebra of the spin-1 "gamma matrices"[22] has been worked out in a covariant form. The formalism has been applied to the electromagnetic interactions of a massive vector particle, and the decomposition of the scattering amplitude into its multipole moments has been carried out. (Klaus D. Rothe)

Relativistic transformation theory[23] of quantum mechanical states containing massless particles was used to study gauge invariance in classical electrodynamics. No new results were found. (Richard Slansky)

The work of Steven Weinberg on the quantization of the gravitational field is being continued. If only physical gravitons are introduced into the theory then it is not known at present how to construct a Lorentz-invariant S matrix describing the interaction of matter with gravitation. Research in this direction is in progress. (Klaus D. Rothe)

Calculations with the covariant version of the Fermi statistical model have been completed. Certain gross features of the proton-proton interactions from 3 to 30 GeV and of the pion-proton interactions from 3 to 16 GeV can be approximated with this model, but the usage of this model to extrapolate these results to higher energies is highly doubtful. These predictions do not agree with cosmic ray data, and many of the lower-energy fits to experimental data seem fortuitous in the light of detailed experimental evidence. (Graham Campbell)

A detailed examination of the errors inherent in the application of an analyticity test[24,25] is in progress. Preliminary results indicate that experimental data of a higher accuracy than is obtainable in the foreseeable future would be necessary to make this test meaningful. (Graham Campbell)

The shifts and widths of the Coulomb energy levels of π-mesic atoms because of the pion-nucleus interaction are being investigated in terms of the continuity of the logarithmic derivative of the pion wave function at the nuclear surface. A model calculation representing the nucleus by a uniformly charged square well has shown standard first-order perturbation theory to be inadequate for the accurate interpretation of level-shift data. Work is in progress on calculating level shifts by extrapolation of pion—whole nucleus scattering data, and, more ambitiously, on construction of the effective pion-nucleus interaction in the bound states from information on nuclear structure and pion-nucleon interactions. (Tom Mottershead)

Studies of the properties of intense beams in storage rings were continued, both analytically and with the aid of digital computation.[26] The work appeared to give an understanding of the various instabilities observed[27] on the 500-MeV Stanford electron storage rings. In particular, suggested modifications in the rings have been successful in suppressing the instabilities up to a current level

which is adequate to do an electron scattering experiment.[27] Further theoretical work is in progress on various aspects of intense-beam instabilities--attempts at understanding phenomena observed at MURA,[28] as well as a study of some of the more detailed observations at Stanford, and investigation of the phenomena to be expected in electron-positron storage rings. Work to data has been reported at a recent conference on storage rings.[29] (Andrew M. Sessler)

The investigation of resistive instabilities of beams in particle accelerators (referred to in the preceding Semiannual Report, p. 25) was completed, and two manuscripts submitted for publication.[30,31] (V. Kelvin Neil, L. Jackson Laslett, and Andrew M. Sessler)

The design of a beta-ray spectrometer with azimuthally varying fields (AVF) was pursued with the aid of digital computation.[32] This work has not yet produced a spectrometer of sufficiently improved properties to merit construction; however, the advantages of AVF have not yet been exhausted, and the study continues. (Andrew M. Sessler)

The investigation of the use of angular correlations in K_{e4} decay to determine the low-energy π-π scattering phase shifts has been completed.[33] It was shown that violation of time-reversal invariance would render the proposed analysis very difficult, except in the case of very special models for the mechanism of the violation. One such model, proposed by Glashow,[34] has a direct bearing on K_{e4} decay, and was considered in some detail. This work was submitted as a thesis to the Graduate Division at the University of California, Berkeley, in partial fulfillment of the requirements for a Ph. D. degree in physics. (Alexander Maksymowicz)

A relationship between the unsubtracted dispersion relation for the π-μ decay amplitude (UDR) and the partially conserved axial-vector current (PCAC) is being studied without any approximation. Two conclusions have been reached: (a) The model proposed by Gell-Mann and Lévy ($\partial_\mu J_\mu^A = \text{const}\ \phi_\pi$) contradicts UDR; and (b) a combined use of the UDR and PCAC hypotheses (due to Nambu) leads to a very small wave-function renormalization constant of the pion field ($Z_3 \ll 1$). (Takesi Saito, formerly Takesi Ogimoto)

An investigation of weak interactions and SU_3 was undertaken. Applications of SU_3 to weak interactions, e.g., time-reversal invariance violation, was studied. (Abraham Bookstein)

Studies were also undertaken into the mathematical foundations of noncompact Lie groups. (Abraham Bookstein)

Ion-optical problems connected with possible improvements in the 184-inch cyclotron beam intensity are under study. These have included examination of a possible scheme for reducing radial betatron oscillation amplitudes (which was found to be defeated in principle by Liouville's theorem) and the possible use of alternating-gradient electrostatic focusing near the cyclotron center, in analogy with the corresponding magnetic focusing used in AVF cyclotrons. The latter possibility looks more encouraging on preliminary study; a more thorough investigation is under way. (David L. Judd)

The ion-optical effects of fringing fields were examined in certain high-gradient dual-purpose magnets which combine momentum analysis and quadrupole focusing. These magnets have been constructed here for a Bevatron experiment now being conducted by Kenneth M. Crowe et al. (Experimental Physics). The usual combination of large gradients and nonnormal entry and exit of the beam center line had not been analyzed previously. Enough work to first order in small displacements and slopes was done to provide a firm basis for digital computation of beam properties. Second-order effects are more complicated and are under continuing study, but do not appear to be essential for the experimental use at hand. (David L. Judd)

An investigation of the passage of very-high-energy (up to 200 BeV) nucleons through matter has been carried out with the use of fundamental nucleon-nucleon cross sections developed by George Trilling, who used experimental data at about 20 BeV together with a form-invariant extrapolation. A model for nucleon-nucleus interactions has been assumed in which the incident nucleon impinges on a sphere of constant-density nuclear matter, and an intranuclear cascade results from successive independent nucleon-nucleon collisions. It is also assumed that at the very high energies of interest the secondary particles are essentially produced in the forward direction. This model provides the nucleon-nucleus cross sections, and these are then used to obtain the development of the cascade in matter. A variety of calculations for the density of secondary nucleons as function of secondary energy, depth and kind of matter, and incident energy have been carried out. The calculations have been extended to include the production of pions by use of another formula developed by Trilling. The production of pions by pions has not been

included for lack of experimental information. A UCRL report of this work is being prepared. (Robert J. Riddell, Jr.)

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VI. ACCELERATOR DESIGN STUDY

A. Introduction

An effort equivalent to four full-time persons from the Theoretical Group has been devoted to the LRL Design Study of a 200-BeV alternating-gradient proton synchrotron. This study has been conducted under the overall direction of Dr. Lofgren, with the support of Dr. Lloyd Smith, in his capacity as Deputy Director of the Study. Other activities of the study are described elsewhere. A substantial effort has also been applied to preparation and editing (Lloyd Smith) of manuscript material for the Study Report now in preparation. Additional theoretical work relating to the Design Study is summarized below.

B. Main Ring Design and Orbit Analysis

Selection of principal main-ring parameters was completed during this period. The greatest attention in the final phase was given to optimizing the design of the Collins straight sections. Modifications to the magnet structure adjacent to these straight sections along lines suggested by Hartland S. Snyder make it possible to lengthen the useful drift spaces between the quadrupoles and to shorten the gaps between the quadrupoles and the AG magnets. Thus one obtains longer length for extraction, etc., a smaller total circumference, and improved orbit properties. A similar treatment of the Collins straight sections was made for the booster design. The precise parameter choices were made by exploring numerous cases with the computer program SYNCH.[35]

The values of the sextupole component required in the magnet units to remove the dependence of the betatron-oscillation frequencies on momentum were calculated along the lines suggested in a report by Lloyd Smith,[36] using orbit parameters of the accelerator computed by SYNCH. With this code the optimal location of the supporting piles to minimize beam response was shown to be at F-D points, and the support pile—beam pick-up transfer matrix, used in studies by Laslett and Lambertson of the control system to correct the closed orbit, was also obtained.

SYNCH has been generalized to permit inclusion of transformations more general than those relating to the usual uncoupled-linear motion. The code can find closed

orbits in the presence of such transformations, and eigenvalues, eigenvectors, and betatron functions of the beam system, with the nonlinear transformations linearized in the neighborhood of the closed orbit. One application of this facility has been to demonstrate that the effect on the closed orbit of the saturation shortening of effective magnet lengths at high fields is quite tolerable.

Conversion of SYNCH to the CDC 6600, with inclusion of certain generalizations, is well under way: the CDC code will permit symbolic referencing not only of orbit transfer matrices representing magnets, drift lengths, etc., as at present, but also of other quantities such as particle coordinate vectors, scalars, misalignment response matrices, etc.

An attempt is under way to develop a theory of misalignments analogous to the theory of gas scattering in synchrotrons. It is hoped thereby to obtain a unification of these two phenomena, as well as formulas or tables permitting easy application to any synchrotron. (A. Garren)

C. Booster Design

The design of the Booster was also settled early in the 6-month period of this report. As with the main ring, many different magnet and long straight section configurations were explored (again with aid of SYNCH). For the main ring, the broad qualitative choice was between π-type long straight section insertions with zero-gradient bending magnets in the ends on the one hand, and Collins insertions on the other, with the decision going to the latter. For the Booster, however, the main split was between a FODO type structure with 6.5-meter gaps in the Collins insertions, and a FOFDOD type structure with 9.5-meter gaps in the Collins insertions. The latter was ultimately chosen, with the same type of modification of the gradient magnets neighboring the Collins insertions as was chosen for the main ring.

Frank Selph also studied some alternative structures currently under investigation at CERN, but these did not appear competitive. (A. Garren and Frank Selph (Mechanical Engineering))

D. Specification of Correction Magnets

A study has been made to determine the strength of the correcting sextupole magnets required to correct for magnet saturation. Shifts in the frequency of betatron oscillations of off-momentum particles due to an octupole component in the main field of the accelerator have been calculated and are acceptable. (Phil L. Morton)

E. Estimation of Ripple and Transient Effects in the Main Synchrotron Magnets

An evaluation has been made of the closed-orbit distortions that may be expected to occur from the spatial variation of field errors in the magnet ring due to ripple in the excitation voltage and to transient current distributions produced by a rising voltage pulse. The analysis shows that, at injection, a voltage ripple that does not exceed 2% will be tolerable (for a maximum orbit excursion limited to 0.5 mm), and, with separate excitation of each superperiod, the transient effects likewise will be well within acceptable limits for the rising voltage wave forms that will be provided by the power supplies. (Frank J. Sacherer)

F. Use of Pickup Signals to Correct the Closed Orbit

A computer program has been developed, and initial runs made, to investigate the possibility of adjusting the structure of the projected AGS on the basis of information derived from beam-pickup signals that specify the position of the closed orbit relative to the accelerator. Through use of a least-squares reduction, the program permits the evaluation of a greater number of corrections than the number of individual pickup stations available to provide input data. In computational tests of the procedure, however, the closed-orbit location is also examined at many additional intermediate points in order to determine whether harmful distortions would be produced at such locations.

To reduce the orbit distortions at such intermediate points, and to reduce the complexity of the corrections that are applied, it has been found desirable to attach some "weight" to the variables that characterize the magnitude of the corrections or, alternatively, to exclude from the solution certain eigenvectors that are ineffective in correcting normal orbit distortions. The latter procedure has been found, in fact, to be the more expedient, since the final corrections in that case are immune to repeated use of the program.

In addition to providing the features noted, the present program permits the introduction of noise in input data that simulate signals obtained from the pickup electrodes; it can also examine the performance that would be obtained if the characteristics of the accelerator differed somewhat from the ideal values specified in the design. It is planned

to make use of these latter features in the future, and preparations are now in progress to adapt the computational work to the CDC-6600 computer. (L. Jackson Laslett)

G. Reduction of Surveying Observations

Continuing assistance has been given to the surveying group in the Design Study Program with respect to the analysis of error propagation in the reduction of data from a primary survey. This work has included checking the existing computational program by means of an independent hand calculation for a simple case. In addition, computational results have been studied, and the possibility of an analytic investigation examined, for the reduction of data from a surveying procedure of the type that the CERN group has proposed for initial alignment of a 300-BeV alternating-gradient proton synchrotron. (L. Jackson Laslett)

H. Other Orbit Studies

Preliminary results have been obtained concerning the effect of drift spaces between the rf tanks of a linear accelerator; these encourage confidence in a design that utilizes a large number of short tanks. Work has begun on adapting an existing computational program to permit a more accurate study of particle dynamics in linear accelerators.

Further progress has been made in the study of slow extraction from the projected 200-BeV accelerator; the results are interpreted as indicating the feasibility of such a system.

Work has been begun in an effort to account quantitatively for the coherent beam instability that has been observed in operation of the MURA 50-MeV electron accelerator. (Phil L. Morton)

35. A. A. Garren and J. W. Eusebio, SYNCH: A Computer System for Synchrotron Design and Orbit Analysis, Accelerator Study Report AS/Theoretical/03, April 10, 1965.
36. Lloyd Smith, Effects of Errors and Correcting Elements on Betatron Oscillations, Lawrence Radiation Laboratory Internal (HEPS) LS-5, Jan. 25, 1961.

MATHEMATICS AND COMPUTING SERVICES GROUP

Kent K. Curtis

During the period of this report (November 1964 through April 1965), members of the Mathematics and Computing Services Group performed the following tasks for the Laboratory research groups.

Accelerator Design

AGS Magnet Design

The study for evaluating field properties of magnet configurations was continued with respect to the ring magnets and extended to auxiliary magnets (quadrupoles and sextupoles). Three magnetostatic codes are available. Of these, SIBYL and TRIM[1] are being extensively employed; the third code, TINKER TOY,[1] while theoretically sound, has not been applied to any practical problems.

The code SIBYL has been the major tool in establishing ring-magnet parameters for the purpose of the design study report. Investigation of various pole shapes has been continued and is expected to continue. Minor improvements have been made in the code. This code is being converted for the CDC 6600.

The code TRIM has been used in investigating magnet geometries for which SIBYL is unsuited. In particular, it has been applied to auxiliary magnet problems which involve asymmetric regions for solution. Some inconsistencies in results still appear, and with the assistance of Dr. Alan Winslow (Livermore), these are being diagnosed. The code is being converted for the CDC 6600. This version will use disk storage and make possible the use of a much finer mesh (approximately twenty times as many mesh points as at present).

The code TINKER TOY was used to test various algorithms, relaxation parameters, and sweep patterns with a nonuniform rectilinear mesh. The other codes having proved adequate, this code was not used for practical magnet design problems. At present no further work with or on this code is contemplated.

Two short codes MEWFIT and GPCOM were written to prepare better tables of permeability and derivatives for use in magnet codes. Some effort has been made to obtain an analytic representation of the permeability as a function of the field in media of low silicon content. (John Colonias, Suzanne Clark, Fred Andrews, James Spoerl, Ardith Kenney, and Bruce Burkhart for Andrew Sessler and Charles Dols)

AGS Orbit Studies

The code CAROUSEL[2] was improved by providing restart procedures when a problem was time-terminated. This feature was found necessary for problems involving high-frequency oscillations. (Penny Collom for Andrew Sessler)

The synchrotron design code SYNCH[3] was improved as follows:

a. Provision was made for designing a straight section with bending magnets in its ends (Macro DKSS).
b. A facility was added for computing betatron functions and equilibrium orbits for beam systems that include nonlinear elements (Macro CYC).
c. Provision was made for wedge magnets in some cases (Macros CFD and DCFD).
d. With the assistance of Carl Quong, a subroutine (NONLIN) was added to solve a system of nonlinear simultaneous equations
e. Provision was made for magnets with unequal effective bending and gradient lengths (Macro MAGA).
f. Minor errors and inconsistencies were removed.
g. Documentation was brought up to date.

This code is being converted for operation on the CDC 6600. (James Eusebio, Herman Owens, Ardith Kenney, and Nancie Lynch for Alper Garren)

AGS Magnet Alignment

The code MAYBE combines all the features of the code ASTRAL,[4] which estimated radial errors in magnet positioning due to radial survey measurement errors. In addition, the new code provides for estimating azimuthal positioning errors due to angular measurement errors. (Penny Collom for James Braley)

The code BABRA computes corrections to be applied to support-pile structure on the basis of beam-pickup information. It is assumed that beam-position information is available from 72 stations situated at roughly equal intervals around the ring. From this

information, reasonable compensatory movement of the pile caps is computed. (Barbara Levine for L. Jackson Laslett)

The code REPROBATE[4] has been improved (to handle larger sets of input) and tested, and is being used to solve the problem of beam-survival probability with two-dimensional beam displacement due to misalignment (Barbara Levine for L. Jackson Laslett)

AGS Utility Programs

A code EIGLIM was written to determine eigenvalues of a matrix associated with an inductance-capacitance circuit. The input involves primary and secondary inductances and coupling coefficients of a transformer, an inductance of a coil, and the capacitance of a condenser for each of several subsidiary circuits. (Jonathan Young and Bob Powell for Henry Lancaster)

A code TISC determines the transverse incoherent space charge limit without neutralization for main or booster accelerators of specified geometry. A tabulation of the limit is computed for various values of bunching factor and kinetic energy. (Jonathan Young for Jack Peterson)

88-Inch Cyclotron

The code INDBPT[5] has been expanded to plot the difference, synchronous field minus average field $[B_s(R) - B_{av}(R)]$ against the radius. The radial positions of the 17 trim coils are shown on the plot.

The code PINWHEEL, written at Michigan State University for the CDC 3600,[6] has been converted for operation on our IBM 7094. The code is being used to study particle orbits in the central region of the 88-inch cyclotron. A CAL-COMP plot for orbits has been added to the code. (Ardith Kenney for Elon Close)

A study of the properties of the beam of the 184-inch cyclotron in the central region of the machine was started. The program for computing particle orbits in the central median plane region of a cyclotron[6] is to be modified to include the motion of the particle out of the plan. (Victor Brady for David Clark)

Beta Spectrometer

The code ISO (a revision of BARS[7]) has been written to further investigate the feasibility of strong focusing in a beta spectrometer. This code attempts to systematically eliminate spherical aberration coefficients. Coefficients up to third order were eliminated, but fourth-order coefficients became very large. Methods of avoiding this difficulty are being sought (Herman Owens for Andrew Sessler).

General Physics Research

Trilling-Goldhaber Group

The program FSDPAK[8] was completed, which generates PACKAGE[9]-type tapes from FOG FORTRAN library tapes. This was done so that FOG data might be processed by existing EXAMIN[10] programs.

The program SELECT[11] was modified to be run in the 65K mode in order to select events from FOG-PACKAGE tapes. This was necessary because of the large number of events contained on a FOG library tape.

SELECT and EXAMIN routines were kept up-to-date with experiments, with format changes in tapes and cards, and with calculations desired by the experimenters. (Bert Albrecht)

Several modifications were made to CHAOS.[12] The control cards were modified for easier processing of large samples of Monte Carlo data. Some minor routines to facilitate special handling were added.

A new EXAMIN program was written for Experiment 08 (K^+ d). It mainly consists of setting type flags, minor calculations, and abstracting PACKAGE quantities.

Several existing EXAMIN programs were updated and some were modified for processing special events.

Modifications were made to the READC[13] program for Experiment 63 FAIR tapes.

A sample of HIST3D CAL-COMP plots was prepared to represent what would be seen from several different eye positions.

Work was started on an EXAMIN program for Experiment 80 (80-inch K + H) and a new version to FILTER[14] for CHAOS. (Emmett Burns)

Initial work was done with existing programs of CHAOS, SELECT, and EXAMIN. This was primarily work with data cards and master lists, gaining familiarity with using the programs, and minor changes to CHAOS.

The CDC 3600 magnet-testing

FORTRAN program, TRAMP, was translated to 7094 FORTRAN. A new scanner monthly time summary and master list accounting series of programs, called WHIP, has been written. (Derik Armstrong)

Work on the 20-inch bubble chamber Experiment 23 has been in the EXAMIN and special job phases. A reexamination of the entire experiment was done with special event-type selections (25 ambiguities) to check for D^+ production.[15] The EXAMIN program K^+ BEAM was used to examine the S(XY) and S(Z) errors in the chamber.

Work was done on a three-view chop-and-choose routine CHOPA for the PANAL[16] program. The residue of unfitted events is being looked at with a special group of neutron target event types in the PACKAGE program.

Initial work has been completed on the new 20-inch Experiment 22. This is a recent π^+ beam run (at Brookhaven) for comparison with the K^+ beam of Experiment 23. Setup and beam-testing subroutines were written for this experiment.[17]

Progress has continued on the 25-inch bubble chamber Experiments 08 and 03. Determination of the beam criterion for the momentum levels A through E has been completed.

Initial work and planning have been completed on the 80-inch bubble chamber Experiment 80 (at Brookhaven).[18] The subroutine SET80 was written for the setting up of the experiment and the chamber constants, and preliminary testing and refining of the optical and field constants was done through a modified version of K^+ BEAM. More precise fiducial testing equations were made available by writing subroutine TSF80 into PANAL and PACKAGE.

Quick initial testing was required for the new 25-inch Experiment 66, presently being run at the Bevatron. This was accomplished, and a setup subroutine, TAPE66, and K^0 beam event type ZET17 were written.[19] It was necessary to obtain an additional constraint for fitting, so the subroutine PLATIN was written to find an average angle and errors from the platinum target to the interaction point.

The following new subroutines were written for general use by all the experiments. To PACKAGE were added MASMIN, a standard deviation from the missing-mass calculation for two missing neutrals, and MMCUT, a logical missing-mass selecting and filtering routine. Subroutine QWRDN and a new version of MAINEP were written into EPC,[20] in conjunction with the previous two subroutines. Also EFFMAS, a calculation of the effective mass between two particles, and EMFIND, a track-selecting subroutine, were written in conjunction with NFNO, which was put into EPC. Event-type subroutines were shortened through the generalized subroutines GUTSAV, GUTPIC, NOPBEM, and KET80. Overlapping of all chamber constants was made possible through the use of subroutine SET728. The subroutine BIGB was added to EPC to keep a running check on measuring efficiency.

Progress has been made in the conversion of Flying-Spot Digitizer data as input to the PANAL-PACKAGE-EPC system. This was done through the initial use of the program TGIF72 to translate and rotate 72-inch HAZE data into PANAL format.[21] (Jim Miller)

Miscellaneous Physics

In the analysis of experimental elastic scattering of strongly absorbed ions, two nonlinear least-squares programs were written in FORTRAN IV. Program PHAST V is a reformulation of a five-parameter fit to elastic scattering differential cross-section data obtained as a function of angle. The newly parameterized function eliminated the high correlations previously found among the parameters. Program SCATAM is a seven-parameter fit to scattering amplitudes defined in terms of partial waves. These two fitting programs plus several special-purpose programs were written to aid in the presentation of this experiment.[22] (Claudette Rugge for Evangelos Hadjimichael, Moyer-Helmholz Group)

Two programs were written to edit data generated by malfunctioning microscopes with automatic recording devices. The program DELFID was written to detect incorrect data cards generated by a microscope whose fiducial encoders were incorrectly adjusted with respect to the measuring engine, and to make the appropriate adjustment. The program ERROR was written to make format corrections to data cards generated by an errant microscope. (Myron Myers for Powell-Birge Group)

A 7094 program FILL was written to read PDP-5-generated tapes, to edit the data, and to generate a FORTRAN BCD tape of packed data. (David Leppaluoto for Claiborne Johnson, Segrè-Chamberlain Group)

A Monte Carlo program POP, which simulates the nuclear event $\pi^0 \rightarrow \gamma + e^- + e^+$,

has been written in order to determine the most efficient counter configuration so that the γ-ray energy distribution is sensitive to small variations of a weighting function parameter. (Bill Dempster for Roy Haddock, Crowe-Haddock Group)

Work was completed on a FORTRAN IV program called ATMOS[23] to be used for calculating the effective atmospheric density encountered by a high-energy proton trapped in the earth's magnetic field. The program computes the particle and guiding-center coordinates, the integral of the atmospheric density and proton energy loss along the particle path, and the integral of the guiding-center atmospheric density along the particle path. The earth's magnetic field is obtained from a 48-coefficient expansion obtained by Jensen and Cain,[24] and the atmospheric density is from a model due to Harris and Priester.[25] The particle and guiding-center coordinates are stored on tape for use with different model atmospheres. The program will also be used to study certain properties of trapped-particle orbits, such as the behavior of the particle pitch angle at the earth's magnetic equator.

A FORTRAN IV program ELOSS was written for the purpose of computing the energy loss probability of a charged particle traversing a thin layer of matter. A routine for evaluating the Vavilov distribution, written by Seltzer and Berger of the National Bureau of Standards,[26] was used as the basis of the program. (Victor Brady for Harry Heckman, Heckman Group)

Spark Chambers

Lofgren Group

A set of DDP-24 programs was written and is currently being used during the installation and checkout of the SASS System. Three general-purpose subroutines were completed and put on the system tape. They are as follows:

(a) SCAN. This program allows the user to scan a rectangular surface, line, or point on film to determine any points or tracks. By use of sense-switch control, the user has the option to save all points observed or save only the mid-points of tracks that the scan crossed.

(b) PLOT. This program allows the user to display a set of points on the DEC-30 CRT and use the light pen to determine the coordinates of any of the displayed points.

(c) LPEN. This program calculates a raster of points and then uses the subroutine PLOT to let the user select a position on the CRT. The program is used to find an initial section of the film to be scanned.

A FORTRAN program, BIG RAY, was written which used the above subroutines to scan a section of film, display the hits on the DEC-30 CRT, or type out the coordinates of the hits. In addition, the program has the option of performing a reproducibility test on any two separated points. (Donald Zurlinden)

A DDP-24 program, MICKEY, was begun to recognize tracks on film via the SASS equipment. A major effort will be made in this program to cut down film-scanning time by using the past history of the track to make an accurate prediction of the location of the next spark and thus allow a short sweep length. (Leslie Wilson)

Crowe-Haddock Group

Work is continuing on the 7094 equipment monitoring program, EMP,[27] for the Crowe Bevatron experiment. Because of lack of core storage, monitoring is now being done in two passes, first on the raw data tapes generated by the PDP-5 and later on reduced data tapes produced from the first pass. Second-pass monitoring will be incorporated into a set of processing routines which now includes an overall event-validation and momentum-fitting program, MFP, a focal-plane Vidicon program written by Edna Williams, and a target-counter program which is being written at UCLA. MFP determines for each event the momentum measured by use of the magnetic field, and determines initial and final conditions for each set of sparks for a given momentum. (William Benson)

Work on the program OLD CROW,[28] a PDP-5 program for use with the Crowe Bevatron experiment, is being continued. The purpose of this project is to produce a monitor program for this experiment. As various parts were completed, they were abstracted from this monitor to be run as temporary programs to aid in the checking of equipment. To date, the program allows data to be gathered on tape and a single event of these data to be displayed on the CRT. This program also has the feature of allowing the tape to be reread and single events reprocessed. (Anthony Schaeffer)

The 7094 program VIDATA was written to recognize tracks in both the target and exit spark chambers of the Crowe Bevatron experiment from Vidicon data. The program TRGTRK[28] was incorporated for the target chambers and modified to also recognize tracks in the exit chambers. A second level of logic was added to the combined program to correlate tracks in pairs of stereo views and

determine space tracks. For the exit chambers, a third level of logic was added, namely, a very careful search for a secondary track.

The 7094 program, CRWEXP, was written to read the two data tapes from the Crowe Bevatron experiment and collect the data from a given event for processing by VIDATA and the monitoring program EMP. (Leslie Wilson)

A 7094 FORTRAN IV subroutine VICVID is being written as a part of the event-validation and momentum-fitting program connected with the Crowe Bevatron experiment. VICVID extrapolates final ion conditions to the focal-plane Vidicon and asks the target-recognition program for that chamber for the observed position and angle of primary and length of primary (in inches of aluminum) in the chamber. This subroutine also derives goodness-of-fit numbers. (Edna Williams)

Moyer Group

A 7094 MAP program CC2TV was written to read files from CAL-COMP plot tapes and scale and plot corresponding pictures on the CRT. (William Benson for David Cheng)

A set of programs, OSCAR, was written to handle punched-card spark-chamber data currently being gathered on the OSCAR scanning and measuring tables. Sparks are given corrected coordinates on the basis of their most probable gap; tracks are found and their equations determined by a least-squares method. (David Snyder)

Modifications to existing DIGRO programs, which edits data from the TRAMP I measuring devices on the assumption of fixed record size, were made to allow for variable record sizes. (David Snyder)

Segrè-Chamberlain Group

Work is continuing on a set of DDP-24 programs which will be used for scanning film for the Chamberlain K-Σ parity experiment. The basic data consist of 35 mm photographs of spark chambers surrounding the experiment.

Chemistry

Modifications to the program BETABLE[29] were made to allow diagonalization of matrices of up to order 62. Two programs, CARNUT and TAPMAK, which prepare input tapes to BETABLE, were written. The new tapes contain information describing rare earth types of atoms in a crystal. Subroutine to allow the use of disk storage is being written. (Thomas Clements for John Conway)

SLOOP is a program that searches for energy levels in atomic spectra. The input data are the energies of atomic emission lines which are known to belong to the same degree of ionization as the element under study. The program takes differences between all the energies in a given range and determines if they are significant. (Marilyn Mahan for John Conway)

MYSTIC, a 7094 program, edits data obtained from counters and determines if any periodicity exists in the data. Results are plotted on the CAL-COMP Plotter. (Marilyn Mahan for Eckart Matthias)

The program STUMBLE was written to determine the value of parameters of the function Γ_b/Γ_n which give the best least-squares fit to measured data. The fitting function Γ_b/Γ_n is the probability density function for fission to take place, rather than neutron boil-off, when an atom is excited. (Marilyn Mahan for Frank Plasil)

The program LAWFIT[30] was modified to allow linear constraints on parameters used in the least-squares fitting by VARMIT.[31] Additional subroutines were added to read in and make polynomial fits to calibration data of various types to help compensate for nonlinearities of the recording equipment. (Leslie Wilson for Marjorie Faltens)

A program UNFOLD has been written to find the numerical solution to the integral equation $D(t) = \int_0^\infty e^{-\lambda} P(t-x)\,dx$, where D and P are measured values and λ is a parameter to be determined. This equation arises from measurements of nuclear decay by the coincedence method. (Eric Beals for Eckart Matthias)

The program DIFFER was written to solve the coupled complex differential equations for scattering of nucleons or α particles from an even nucleus in which the coupling between the excited states of the nucleus is explicitly introduced.

The program CROSS was written to compute the cross section of elastic and inelastic scattering, using the scattering matrix obtained from DIFFER. (Noel Brown for Norman Glendenning)

MICRO is a program being written to calculate the coupling terms for inelastic

scattering of nucleons or α particles, based on a microscopic description of the nuclear state. (Edna Williams for Norman Glendenning)

Given the liquid-drop formulation of fission probability as discussed by D. S. Burnett,[32] an IBM 7094 FORTRAN IV program called PEAX was written which calculates the correction made in the mass—kinetic energy distributions when isotropic neutron emission is included in the calculations. Mass—kinetic energy probability maps with their 0→3rd statistical moments plus the full width at half maximum are printed both before and after neutron evaporation. By use of tables of average binding energy and average energy release as a function of fragment mass as calculated by program MASSION,[33] results have been obtained for $W^{182} + He^4 = Os^{186}$, and they agree favorably with calculations made on experimental data. Further cases are to be run for future publication. (Claudette Rugge for Frank Plasil)

A new method has been developed to investigate hyperfine magnetic fields at nuclei of impurity atoms in ferromagnetic lattices. It consists of a measurement of the perturbation of an angular correlation by the magnetic fields. This new theory was applied to a completely demagnetized source of Cd^{111} in Ni, which reduces to a special case in which the time-dependent magnetic interaction frequency can be measured directly as a function of one angle. A FORTRAN IV program, COS6, was written which fits time-differential measurements of a random magnetic interaction to a nonlinear function of six parameters. The results have been reported.[34] (Claudette Rugge for Eckart Matthias)

Several functional forms involving even and odd Legendre polynomials of up to order 10 were tried in the nonlinear least-squares fit of fragmental angular distributions obtained under fission. (Claudette Rugge for Harold Britt)

Work was completed in determining the geometric effects on the distribution of coincident fission-fragment trajectories arising from a disk source of arbitrary size. The case in which two disk detectors of equal size are equidistant from and coaxial with the source was considered, and the distribution calculated. The results are given in UCRL-11965.[35] (Paul Concus and Rand Watson)

Work was begun on a method for calculating the hydrodynamic flow of a uniformly charged incompressible liquid drop. The flow has application in the liquid-drop model of nuclear fission. (Paul Concus and William Dempster for Stanley Thompson)

A 7094 program MIN1, 2, 3, 4 has been written to determine the least-squares fit, to observed energy levels of various nuclei, of certain functions involving Swiatecki mass-formula constants. The basic treatment is that of centrifugal stretching, due to Diamond, Stephens, and Swiatecki and modified by Clarkson.[36] (David Leppaluoto for Jack Clarkson)

Inorganic Materials

Inorganic Chemistry

The program FIAT has been written to determine the parameters of a given equation which gives the best least-squares approximation to nuclear magnetic resonance data. (Eric Beals for Daniel Fiat)

EEMISS is a program which analyzes the results of a series of experiments in vacuum thermionic emission from monocrystalline tungsten surfaces. The maximum electron current J that can be drawn from a metal surface at temperature T is given by the Richardson-Dushman equation $J = AT^2 \exp(-e\phi/kT)$. J and T are measured; k is Boltzmann's constant; A, a constant, and $e\phi$, the electron barrier, are the quantities to be determined by the method of least squares. (Edna Williams for Daniel Koenig)

Metallurgy

A 7094 FORTRAN IV program, CASSINT, was written to numerically integrate the differential equations used by Howie and Whelan[37,38] in describing the contrast observed at crystal defects in thin films examined by the technique of transmission electron microscopy. The term describing the local disruption by the defect of the crystal lattice appears as a variable coefficient in the equations.

The defects being studied are edge and screw dislocations, and pairs of closely spaced edge and screw dislocations. Various approximations to the local strain fields are being used in order to determine the effect of the boundary conditions of the strain fields on the calculated quantities, the transmitted and diffracted intensities. In addition, these quantities are being calculated for pairs of opposite-signed dislocations as a function of their spacing. The aim, in this case, is to see how close such dislocations may lie before their strain fields cancel. When the strain fields cancel, the dislocation pairs will

have little effect on the transmitted and diffracted intensities, and will become "invisible" in the electron microscope. (Edna Williams for Thomas Cass)

The program TRIC was written, which predicts positions of reflections from both matrix and twin regions for various orientations of cubic crystals. (Ardith Kenney for Om Johari)

Plotted output via the CAL-COMP Plotter was incorporated into the programs CLOSET and DIFFUS[39] previously written to solve the ternary diffusion problem and a special linear case thereof. Each of these programs predicts the fractional concentrations of each substance at a given point in the system as a function of time, given the initial conditions and the intrinsic diffusion coefficient of each substance.

The program INFUS was written to find the intrinsic diffusion coefficient of each substance, given the fractional concentration of each substance at a selection of points in the system at some given time. Those values of the coefficients giving the best least-squares fit to the data were considered to be the solution. (Leslie Wilson for Yasumichi Oishi)

Biology

Work on problems of biological interest was sponsored in this period by four organizations: Math and Computing, Biomedical Research, Biodynamics, and Health Physics. Activity continued to be centered on the derivation and analysis of mathematical models of physical and biological phenomena, with heavy emphasis on comparison with experimental data. The models include simple survival and compartmental models, models based on convolution operator representations, and models given by systems of integro-differential equations. Computations ranged from common curve fitting to the determination of parameter vectors appearing in highly complex forms. Theoretical investigations included the foundations of mathematical modeling, biological compartmentation, strontium and calcium, kinetics, erythron and neutrophil proliferation, and kinetics. These represent original research.

The following is a list of Grove C. Nooney's lectures prepared and delivered and papers published or accepted for publication in this period.

1. Models of Blood Cell Proliferation, invited lecture to the Fifth IBM Scientific Computing Symposium, Yorktown Heights, New York, 1964.
2. Iron Kinetics and Erythron Behavior (UCRL-11879, Jan. 1965), submitted to the Biophysical Journal.
3. Mathematical Models, Reality, and Results, to appear in the Journal of Theoretical Biology, 1965.
4. The Vitality of Mathematical Models, presented to a special seminar of the Biomathematics Department of M. D. Hospital and Tumor Institute, Houston, Texas, March 11, 1965.
5. Remarks on the Determination of Parametric Models, invited lecture to the Third Annual Symposium on Biomathematics and Computer Science in the Life Sciences, Houston, Texas, 1965.
6. Mathematical Models in Medicine: A Diagnosis, to appear in the Journal of Chronic Diseases, 1965.

A more detailed statement of progress follows under the appropriate sponsorship headings. Entries in the foregoing list are referenced by number.

Math and Computing

The foundations of mathematical models in biology and medicine were investigated and a diagnosis, a recommended treatment, and a prognosis for such models were described (3, 4, 6).

A method for objective allocation to theory and to experiment of any discrepancy between them was devised, together with appropriate mathematical formalism. This method permits also the quantitative determination of the reliability of theory relative to experiments (5).

A new mathematical model of neutrophil kinetics was constructed including the proliferative and maturative behavior of the neutrophil. This model includes explicit age-dependent transfers between tissues and blood (1). (Grove Nooney)

Biomedical Research

Analysis of patient data on blood iron kinetics proceeded with the use of linear compartmental models and the program SAAM 22 (National Institute of Health). Parameter determination by this means yielded ill-defined models for certain disease states. Modification of the model is in progress to obtain acceptable descriptions of normal states, after which extensions will be implemented to include disease states. (Jerry Borges, Mark Horovitz, and Kenneth Wiley for Harry S. Winchell)

Modifications of SAAM 22 now permit

better weighting of experimental data, as well as automatic plotting of data and results. (Kenneth Wiley for Harry S. Winchell)

The study of albumin kinetics continued with the determination of compartmental parameters associated with the transfer of albumin and transferrin from plasma to lymph. (Eric Beals for Harry S. Winchell)

Data from the whole-body counter and from plasma, feces, and urine determinations, all relating to calcium or strontium kinetics in the human, are being analyzed with the help of a simple compartmental model. (Penelope Collom and Mark Horovitz for Thornton Sargent)

Preliminary study has been made of a more suitable model of calcium and strontium kinetics in primates and humans. (Mark Horovitz for Thornton Sargent and Patricia Durbin-Heavy)

Statistical analysis of radioactive calcium deposition in the rat skeleton continues. (Jerry Borges and Mark Horovitz for Patricia Durbin-Heavy)

Comparisons have been made of various theoretical descriptions and experimental results for the survival of cells that have been exposed to radiation. (Eric Beals and Mark Horovitz for Charles Tobias)

Biodynamics

Methods for testing various hypotheses of biological compartmentation were devised and described in an appendix, "On Interpreting Compartmentalization Experiments," which was submitted for publication with its host[40] in the Journal for Theoretical Biology. (Mark Horovitz and Grove Nooney for Vivian Moses)

A program, MCD, was written to analyze and plot data from a magnetic circular dichroism experiment. (Jerry Borges for Edward Dratz)

Health Physics

Three programs, WILCAL, WILLAG, and WILLIS, were written and used in the calibration of an organic scintallator and in the calculation of the energy spectrum of neutrons impinging on the scintillator. The first program calibrates the scintillator's response to Compton scattering by electrons. This information is then related to the effect of recoil protons produced by the primary neutrons. Neutron spectra are obtained by the parametric solution of a singular integral equation by means of a least-squares determination using either a damped Laguerre polynomial (WILLAG) or a Fourier series (WILLIS) representation. (Marjory Simmons for Willis Young)

Work was completed on the programs FLUXS, FLUXP, and FLUXC[41] for the simultaneous determination of neutron flux by data from various detectors. (William Dempster and Mark Horovitz for Arthur Kohler)

A program WAPLOT was written to compute and plot secondary x-ray spectra measured with a sodium iodide crystal. The primary radiation consisted of neutrons generated by accelerator bombardment. The output from this program is intended for use with the FLUX programs mentioned above. (Marjory Simmons for William Wadman)

Work continued in numerically solving a Volterra integral equation of the first kind arising in the field of radiation dosimetry. The method currently being tried involves finding the best least-squares solution in terms of a truncated series of suitable orthogonal functions. (Paul Concus and Marjory Simmons)

The program HERMIT, received from the AEC Health and Safety Laboratory in New York, was analyzed and corrected for programming and mathematical errors. HERMIT calculates the neutron energy spectrum from the proton recoil spectrum by the numerical solution of the Volterra equation of the first kind. (William Dempster for Wade Patterson)

A 650 program, RECOILIP,[42] has been rewritten for the 7094. RECOILIP calculates the proton recoil energy spectrum from proton tracks in an emulsion that has been exposed to a neutron source. (Edna Williams for Wade Patterson)

ISO, a 7094 program, simulates the rotation of a sphere in a beam of particles to obtain isotropic exposure. The equations of the sphere's motion are given and the coordinates of a point fixed on the sphere are tabulated for each increment in time. (David Leppaluoto for Palmer Steward)

Electronics Engineering

PLOTOR was written to compute and plot contour levels of magnetic field measurements. The measurements are normalized to the field at the center of the magnet and the (X, Y) intercepts of specified intervals are computed and plotted on the CAL-COMP Plotter.

Work was begun on PLOTOR 2. This

is a modified version of PLOTOR which will increase the density of magnetic field measurements by means of least-squares fits to the measured field values.

CERTFY[43] was rewritten to be compatible with major modifications made to the rapid mapper.[44] The data format and CERTFY itself have been made flexible enough to handle all types of data taken by the rapid mapper. In connection with the new version of CERTFY, several programs and subroutines auxiliary to CERTFY were rewritten:

FIXIT[43] is a program which through data card options will make corrections to field measurements, provide computations that are not available in CERTFY, provide printouts of data and calculations, and update the data tape generated by CERTFY.

GEN produces condensed versions of CERTFY auxiliary tapes more suitable for use by persons outside the Magnet Test Group and this Laboratory.

BLEV was written to be called by CERTFY and FIXIT. This subroutine levels a CERTFY map of magnetic field measurements taken at (X_i, Y_i) coordinates to more accurate measurements taken at a reference point (X_i, Y_{REF}) at the same elevation and current level of the original map. Leveling may be by means of the difference between the original measurement and the reference point measurement or by the ratio between the two points. (Bert Albrecht for Peter Watson)

AGRISETIME is a 7094 program which determines the rise time and energy requirements of a pulsed inductive load. It also accounts for source voltage regulation and saturation effects, as well as determining acceleration, "flat-top," and inversion conditions for a rectifier-converter power supply. (Edna Williams for George Farly)

Budget

Revisions were made in the SKED92 Budget Program.[45] New features provide additional support headings, account, and program totals on the man-year and effort detail tables. (Ardith Kenney for George Pappas)

Mathematics and Computing

General-Purpose Programs

A format-free input subroutine, DATA,[46] originally written at Livermore, has been rewritten in FORTRAN 66. This subroutine provides a more flexible method of reading input data than FORTRAN-read statements. (William Benson)

PPLT and CVSK are FORTRAN IV subroutines which were written to allow the plotting of data on the printer.

The subroutine DPMP, a double-precision version of the SHARE routine MATINV, has been written in FORTRAN IV and in FORTRAN 66. This routine finds the inverse of a given matrix by Jordan's method with pivoting. (James Spoerl)

A technique (Leverrier's method) for finding eigenvalues of arbitrary matrices has been studied. The coefficients of the characteristic equation can be easily determined by this method and the desired eigenvalues can be calculated by a root-finding routine. For symmetric matrices, this method is slower than other techniques, but has the advantage of remaining stable for multiple or close eigenvalues.

A study of the eigenvalues of matrices of the form $M=\begin{pmatrix} A & B \\ -B & -A \end{pmatrix}$, where A and B are symmetric submatrices, is being continued. Necessary conditions for the eigenvalues of M to be real have been found. (Harold Hanerfeld)

Three programs have been written to find a local minimum of a given function. VARMIT uses the method described in the report by Davidon.[47] COGMIN minimizes a function by the conjugate gradient method due to Fletcher and Powell, and MINSER utilizes a nongradient method due to Powell for function minimization. (Eric Beals)

The program CHAOS 3D[48] was modified for general use. Given an array of points representing a three-dimensional histogram, CHAOS 3D will draw on the CAL-COMP Plotter a two-dimension perspective picture of the histogram as seen from various eye positions. (Noel Brown)

A 7094 program LNGAM4 has been written to evaluate the function $\log_e[\Gamma(Z)]$ for complex arguments.

LEGPOL is a program which evaluates the Legendre function for real arguments and a given order. (Marilyn Mahan)

Work is continuing on the set of two programs, AUDIT 1 and AUDIT 2,[49] and a third, AUDIT 3, was begun for the purpose of keeping cost and time records of all problems run on all LRL Computers. AUDIT 1 accepts time cards, edits the information on the cards,

and produces a corrected data tape. AUDIT 2 is a report-generating program, and will produce a report for any selected computer for any specified period. AUDIT 3 provides the capability of updating the corrected data tape. (Krehe Ritter)

Work was completed on developing refinements to an iterative procedure to find the numerical solution of a two-dimensional quasi-linear elliptic partial-differential equation arising in magnetostatic problems, and a report is being written.

Assistance was given to various members of the Laboratory in solving mathematical and computational problems in which they were interested. (Paul Concus)

A series of classes on FORTRAN programming were organized for Laboratory personnel. Five courses were given with a total enrollment of 106 students. The Laboratory Computing Facility was made available to the students, who wrote and debugged computer programs. (Carl Quong and Myron Myers)

Systems Programming

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

I. 1401/1460 Systems

A. 7044/7094 support

1. A revision to the MONITOR CARD-TO-TAPE program was written which prints the run sheet (which previously was typed by the operators), checks all Hollerith cards for invalid punch sets, separates decks on the basis of ID cards (instead of end-file cards), and checks ID cards for proper format (decks with improper ID cards are not placed on tape).

This program processes about 800 cards/minute. (Walter Hutchinson)

2. The FILE MERGE and TAPE DUMP programs were improved and corrected. (Gordon Sutherland)

B. 6600 support

A program, 1612-1403 CONVERTER, was written to process print tapes from test runs on the 6600 in Los Angeles. This program outputs to printer or to tape (in a format suitable for printing with the 717 SIMULATOR). It replaces the 1612 characters] and [(which do not belong to the 1403 print set) with apostrophes. The processing rate is about 500 lpm on a 1460. (Walter Hutchinson)

C. General

1. The program NOSOAP was written to detect certain errors in SOPAT source decks which SOPAT does not catch.

2. SOPAT was modified slightly.

3. A CORE DUMP program was added to the 1401/1460 system tape.

4. System tape editing has been facilitated by the addition of a program SYSLIST, which lists the contents of the system tape, and the reworking of the programs which form, update, load, and copy the system tape. (Walter Hutchinson)

5. A program, DOB, was written which converts rapid mapper output paper tape to magnetic tape with printing and special formating. (Robert Belshe)

II. 7040/7044 Systems

A. The LRL version of the 7040/7044 IBSYS monitor system was modified to facilitate IBSYS runs on the SMP 7040.

B. A set of clock routines compatible with the 7094 routines CLOCK I, CLOCK D, and CLOCK T routines was added to the system library.

C. The standard LRL CRT package (J5 EO 94PL and J5 EO 94GR) was modified to run on the 7044 and produce a CRT tape similar to the one produced on the 7094B. (David Stevens)

III. 7094 Systems

A. Several small improvements were made to the LRL versions of the 7090/7094 IBSYS Monitor. [Robert Belshe, Myron Myers, and Doneley Watson (IBM)]

B. The interrupt generator for the 7094A Channel H clock was completed and checked out. (Robert Belshe)

C. A program, F4DISK, was written to allow FORTRAN users access to the disk for matrix manipulations. The routine is easily adaptable to special cases, and several versions now exist. (Myron Myers)

D. An investigation was begun of the feasibility of modifying Version 13 of 7094 IBSYS (the FORTRAN compiler, in particular)

for use with diprogramming. (Doneley Watson)

IV. 6600 Systems

A. Investigations and Proposals

1. A proposed set of specifications for a sophisticated programmer file storage and updating system, with emphasis on remote console control, was submitted to Control Data Corporation for implementation in the 6600 SIPROS operating system. (Jane McDonald)

2. A set of functional specifications for a magnetic tape labeling system was prepared and submitted to CDC and the newly formed 6000 Series User's Group (Samuel Penny)

3. A systems analysis was run on the disk-handling procedures utilized by the 6600 SIPROS operating system. It was discovered that these procedures are not optimal, and, in fact, might seriously degrade the performance of the whole system. A report of these findings, together with suggestions for improving the system, was sent to CDC. (Samuel Penny)

4. Specifications for a PPU program to drive the CDC 250 display system are being written and techniques developed to allow use of the full capabilities of the system. (William Benson)

5. Some preliminary investigations into the most effective use of the DD-10 remote console system on the 6600 were begun. (William Benson and Myron Myers)

6. The problem of multiprocessing within a PPU is being investigated. The objective is the development of a set of standard PPU subroutines which interact with a standard PPU monitor to operate several asynchronous devices (at nearly maximum capacity) in a multiprocessing mode. (Walter Hutchinson)

7. A system to perform 7094 support on the I/O module of the 6600 is being designed. (Jerry Borges)

8. An investigation was conducted of the feasibility of using the Teletype synchronizer designed by Livermore (for use with Octopus) with our 6600 System, with the result that such a synchronizer is now under construction at LRL, Berkeley. (Robert Belshe)

9. A detailed report comparing the three versions of FORTRAN now in use at LRL (FORTRAN II, 7044 FORTRAN IV, and 7094 FORTRAN IV) with FORTRAN 66 was prepared and published in the Computer Center Newsletter (Vol. 2, No. 3). (David Stevens)

B. Programs

1. A SAMPLER for FORTRAN 66 was written. (This provides compilation samples of legal types of statements, supplies information on subroutine linkage and calling sequences, demonstrates the diagnostic message produced by many of the more common errors, and answers many of the questions left open by available manuals). (David Stevens)

2. A FORTRAN IV program, TIMER, was written to provide timing information for programs written in the 6600 ASCENT language. (David Stevens)

3. A FORTRAN IV subroutine SIMPPU was written to simulate one or two 6600 PPU's on a 7044 or 7094. A FORTRAN 66 version (to run on a 6600) has also been written and is now being debugged. (David Stevens)

4. A FORTRAN IV program PPUPER was written (for use in conjunction with SIMPPU) to assemble programs written in the 6600 ASPER language. A FORTRAN 66 version of this program is being prepared. (Myron Myers)

5. CAL-COMP and CRT display routines are being revised and rewritten for the 6600. (Coding is being done in FORTRAN whenever possible.) (William Benson)

6. Work was begun on a preliminary version of a programmer file storage and update system. (Jane McDonald)

7. A PPU program to drive all teletypes, three CAL-COMP Plotters, and a set of remote displays for tape drives is being written.

8. A PPU program to handle teletype messages (both incoming and outgoing) is being written. (Douglas Brainard)

9. A software package to permit debugging of teletype programs before teletypes are actually available is being designed. (Douglas Brainard)

Other Activities

Evaluation studies were carried out

with Dr. Margaret Alston for the selection of a mass storage device (3.3×10^{11} bits capacity) for use of the Laboratory. IBM was chosen as the vendor of such a device, and contract negotiations are now under way.

Part of the evaluation involved simulating the mass store as it is expected to be used at LRL. It was determined that the IBM device should be satisfactory in throughput, as well as capacity, both for use in bubble chamber analysis and as a medium for user data files now kept on magnetic tape or cards. (Samuel Penny)

David Stevens served as Chairman of a committee of the SHARE FORTRAN project, which prepared and published (through SHARE) an extensive comparison of the 7044 and 7094 versions of FORTRAN IV.

Laboratory personnel were instrumental in organizing the first meeting of a proposed CDC 6000 Series Equipment Users' Group. Robert Harvey was elected Chairman.

Small Computers

I. DDP-24

A. The LRL Loader was modified to operate with the new blocked-format system tape.

B. An edit program was written to facilitate system program maintenance.

C. A magnetic tape update program for symbolic tapes was written and checked.

D. FORTRAN—the magnetic tape version of the FORTRAN Compiler—was received from Computer Control. Modifications and corrections were inserted to make it run with the LRL machine configuration. (Robert Belshe)

A DDP-24 magnetic tape—to—paper tape program was written for the Alvarez Group. (Anthony Schaeffer)

A DDP-24 paper tape—to—magnetic tape program was written for Bob Harvey to be used for processing data from the 88-inch cyclotron. The magnetic tape is used as input to the 7094 program, DIABLO.[49] (Anthony Schaeffer)

II. PDP-5

A light pen tracking routine was written for the PDP-5. It enables the user at the computer console to alter the graphs being displayed on the Tektronix Display Scope and manipulate displayed items. Such information as the coordinates, of the items, the last item referenced by the light pen, etc., are transmitted back to the user's computer program. (Myron Myers)

A PDP-5 simulator, ASSIM, written in the FORTRAN IV language, was completed. It permits PDP-5 programs to be executed which use the keyboard, teleprinter, and oscilloscope. In addition, a debug package for use with the simulator was written. The debug options include dumping areas of memory, zeroing areas, tracing the program (to a location or indefinitely), not tracing the program, terminating the pseudo-execution, and displaying the accumulated oscilloscope buffer. Each debug option has an associated location such that when the instruction at that location is executed, the debug option is examined. In addition, a debug option has an iteration count that is similar to the limits in a FORTRAN DO statement. For example, the user can specify that a given debug option be exercised every third time the location is reached, starting with the fifth line. (Myron Myers)

Miscellaneous improvements were added to the PDP-5 assembler (7090/7040), the PDP-5 debug system, magnetic tape routines, and interpretive program. (Anthony Schaeffer)

A PDP-5 double-precision fixed-point logarithm routine has been written for Lloyd Robinson (Nuclear Chemistry). The routine may be used only on the PDP-5 Serial Number 54 (at Building 88) which is equipped with the fast multiply and divide special feature. (William Benson)

III. PDP-7

A study of small computers for the Chemistry Department was completed, and the PDP-7 was chosen as the most applicable. Planning is under way to develop a time-sharing system for this computer so that several pulse-height analyzers can be computer-controlled by distinct programs simultaneously, while at least one other program is doing background analysis on already gathered data. In addition, a program is being written in the FORTRAN language which runs on the IBM 7094 or 7044. This program will both assemble a symbolic PDP-7 language program and simulate the execution of this program. (Myron Myers)

Computer Operations

In November 1964 the Laboratory made its decision to acquire the Control Data Corporation's 6600 Computer, and this decision was approved by the AEC in January 1965. The machine configuration has been selected and site preparation for Building 50A is in progress. Specific units of IBM equipment

have been selected to be moved to other Laboratory buildings or released to IBM. Two additional CAL-COMP Plotters have been purchased for use with the 6600.

Arrangements have been made for the Laboratory to begin checking of programs at the Control Data Corporation's installation in Los Angeles. It is expected that the turnaround time will be less than 24 hours.

Preliminary and semifinal drawings were checked and revised for Building 50B Computer Room, I/O Room, Tape Vault, Library, Quiet Ready Room, Noisy Ready Room, and Key Punch Room. (Paul Rhodes and Marvin Atchley)

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PHYSICS RESEARCH

Edward J. Lofgren in charge

p-p ELASTIC SCATTERING

Allan R. Clyde, Bruce Cork, Denis Keefe, Leroy T. Kerth, William M. Layson,[1] and W. A. Wenzel

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

A paper on this subject is being prepared for publication.

$\Sigma\Lambda$ RELATIVE PARITY

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

A polarization measurement in spark chambers has been completed on Σ^0's produced in $\pi^- + p \rightarrow \Sigma^0 + K^0$ in the π^- momentum region 1200 to 1400 MeV/c. A measurement of the $\Sigma\Lambda$ relative parity was planned, using Dalitz decays of the Σ^0's. The parity measurement requires polarized Σ^0's. While the Σ^0 polarization appears to be generally large, although of opposite sign for forward and backward Σ^0 production, there will probably not be enough Dalitz decays to permit a parity measurement. Measurement of the Dalitz decay events is expected to be complete in about 3 months.

K^--p INTERACTION

Edgar F. Beall,[2] William R. Holley, Denis Keefe, Leroy T. Kerth, John J. Thresher,[3] Ching Lin Wang, and W. A. Wenzel

The analysis of the data of the elastic scattering and the recoil-proton polarization collected on K^--p interactions between 700 and 1400 MeV/c has been completed.

The K^--p elastic differential cross sections were obtained at 15 incident momenta, and recoil proton differential polarizations were obtained at five incident K^- momenta. A single-energy phase-shift analysis was made with the data obtained here. Furthermore, an energy-dependent phase-shift analysis was made by utilizing all available data on the K^--p total cross section, differential cross section, charge-exchange cross section, and K^--n total cross section between 110 and 1400 MeV/c.

Both the results of single-energy and energy-dependent phase-shift analyses are in agreement with the suggestions of a single $F_{5/2}$ resonance for the 1815-MeV bump in the K^--p total cross section, although a $D_{5/2}$ assignment can fit the data equally well. A $D_{3/2}$ assignment is less favorable. 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.

π-π INTERACTIONS

Denis Keefe, Leroy T. Kerth, Carl M. Noble, John J. Thresher,[3] W. A. Wenzel, and T. F. Zipf[4]

A spark chamber momentum spectrometer was used to investigate the process $\pi^- + p \rightarrow \pi^- + \pi^+ + n$ at incident momenta of 4, 3, and 2 BeV/c. The data have been completely measured, yielding $\approx$ 1500 low-momentum-transfer events at each incident momentum. The π-π invariant mass spectrum shows two enhancements, at 715 and 800 MeV. The 7094 programs to calculate the geometrical corrections, weighting factors, kinematical constraints, and data distributions are debugged and working.

Interpretation of the final data and preparation of reports are under way.

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

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

An experimental study of proton-proton interactions has been completed at the Bevatron and reduction of the data has begun. Data were obtained on the processes

$$p+p \rightarrow p+p, \quad (1)$$

$$p+p \rightarrow p+N^*, \quad (2)$$

$$p+p \rightarrow \pi^+ + d, \quad (3)$$

and

$$p+p \rightarrow K^+ + \Lambda + p \quad (4)$$

at lab angles between 9 and 70 deg and incident momenta from 3 to 7 GeV/c. Elastic and quasi-elastic proton-deuteron cross sections were also measured with the same apparatus, which is fully described elsewhere.[5] Evidence for a low-energy enhancement in the (Λ - p) missing-mass distribution of Reaction (4) is of special interest, as is the behavior of the production angular distributions for the various N^*'s in Reaction (2).

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

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

A spark chamber experiment to measure with good statistics the diboson spectrum up to masses larger than that of the f^0 (1250 MeV) has been accepted by the Bevatron scheduling committee. The reactions to be studied include

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

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

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

and

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

with the incident pion momentum varying from 2 to 5 BeV/c. Several regions of particular interest are the K^+K^- spectrum in the vicinity of the f^0 and the $\pi^+\pi^-$ spectrum in the ρ region (700 to 800 MeV). Results from a previous experiment by this group[6] showed significant structure in the dipion spectrum near the ρ mass. This experiment will increase considerably the statistics in this region, and also provide better measurement precision.

Developmental work on the apparatus has been started.

The experimental run at the Bevatron is scheduled to start in November 1965.

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

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

(b) Remeasurement of α for $\Sigma^+ \rightarrow \pi^0 + p$, and accurate determination of β and γ for this mode.

(c) Remeasurement of α $\bar{p}$ for the above modes.

(d) Measurement of the branching ratio for $\Sigma^+ \rightarrow p + \gamma$.

(e) Measurement of the rare decay modes $\Sigma^\pm \rightarrow \pi^\pm + n + \gamma$, if background permits.

The experiment is scheduled to start at the Bevatron in July 1966.

SCANNING AND MEASURING EQUIPMENT

Leroy T. Kerth

The SCAMP measuring projectors have been under three-shift operation and are in use by three groups at LRL.

SASS, an automatic scanning system for spark chamber photographs, is almost in operation. The hardware is in operating order; however, there will be some nominal modifications before production running can commence. Programming is $\approx$ 95% complete for some first attempts to scan spark chamber film taken by the Chamberlain group. The system should be in operation and producing data by September 1965.

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* Presented at the International Conference on High Energy Physics, Dubna, USSR, Aug. 5-15, 1964.

1. Presently at Pan American World Airways, Guided Missile Range Division, Patrick Air Force Base, Florida.
2. Presently at the University of Maryland, Department of Physics, College Park, Md.
3. Work performed while on leave from the Rutherford High Energy Laboratory, Chilton, Berkshire, England.
4. Presently at Brookhaven National Laboratory, Upton, Long Island, New York.
5. C. M. Ankenbrandt, A. R. Clark, B. Cork, T. Elioff, L. T. Kerth, and W. A. Wenzel, Orthogonal Dispersion Spectrometer for Missing Mass Spectra, UCRL-11995, April 1965.
6. D. Keefe, L. T. Kerth, C. M. Noble, J. J. Thresher, W. A. Wenzel, and T. F. Zipf, Di-Pion Mass Spectrum from π^--p Collisions at 4 BeV/c, UCRL-11468, July 1964.

PHYSICS RESEARCH

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

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

Brenton Stearns, Robert Kenney, Richard Eandi, and David Caldwell

An experiment is being prepared at the 184-inch cyclotron to measure the lifetimes of π^+ and π^- mesons, in order to provide a better check on CPT invariance. The recent observation of the CP-violating decay $K_2^0 \rightarrow 2\pi$, combined with the existing checks of T invariance, provide a motivation for investigating the validity of CPT invariance. Although violations of CPT would have extensive theoretical consequences, the experimental tests of its validity are insensitive compared with the level of the observed CP violation. The equality of particle-antiparticle masses is a poor test of CPT in weak interactions, and comparative lifetimes of particles and antiparticles are known to a few percent at best. In addition to comparing the π^+ and π^- lifetimes, we plan to measure the decay distributions in sufficient detail to find any deviation from an exponential form, such as suggested by Goldberger and Watson for particles which are not simple poles.

The method is simply to count a beam of momentum-analyzed pions as a function of distance from the target in which they are produced. The pions are distinguished from decay muons by a focusing Cerenkov counter having liquid hydrogen as the Cerenkov medium. Such a counter requires that a particle have not only the right velocity, but also the correct direction. It is essential that the pion beam be contained entirely within the Cerenkov counter at all positions, and a counter-defined beam, held together by quadrupoles, is used. The beam distribution can be checked at each position with a portable spark chamber system, which also serves to measure the momentum distribution when used in conjunction with a hodoscope in front of the analyzing magnet.

The equipment is now being fabricated and will be tried at the cyclotron during May. Checks on pion beams from the cyclotron were made in March and the results of these tests influenced considerably our final design.

WIDE-GAP SPARK CHAMBER DEVELOPMENT

Albert Stetz

Our work is directed toward the realization of a large-scale wide-gap helium-filled spark chamber as a functional experimental tool. So far we have obtained adequate results in the projection mode, using small pilot models operated at atmospheric pressure. Investigations of the arrested-streamer mode, with spark-gap and transmission line techniques, are currently under way.

Since we are interested in using the analyzing power of helium nuclei to measure the polarization of nucleons, we have begun a comprehensive phase-shift analysis, in collaboration with David Roper at Livermore, of all the existing data on elastic scattering of nucleons by helium. The analysis is currently complete up to 12 MeV.

Several experiments are planned for the wide-gap chamber, including a calibration run to take proton-helium scattering data, and an experiment to measure recoil neutron polarization in intermediate-energy pion-nucleon charge-exchange scattering.

INSTRUMENTATION

Victor Perez-Mendez

A. Vidicons

The specifications for a third Vidicon system to be used in analyzing the film from the neutron polarization in pion charge-exchange experiments have been drawn up. The Vidicon logic has been modified in the following ways. The number of scalers has been increased to allow for the possibility of scanning eight sparks per gap. Since we are scanning film and hence there is no need for rapid frame times, the scanning sweep speeds will be reduced to 100 microsec per sweep, which together with the 40-Mc scalers will permit a digitizing accuracy up to one part in 4000.

The fiducial system for gap location will be changed to allow for the scan of the

pictures from the cylindrical recoil chamber as well as those from the flat-plate γ-ray chambers.

B. Magnetostrictive Wire Chambers

The characteristics of the magnetostrictive signals from the output of test chambers with aluminum wires and with photoetched copper-plated lines has been studied with the aim of improving the two-spark resolution. This has now been brought to less than 2 mm with an accuracy of spark location of 0.1 mm.

Four wire chambers with this readout are being made for use in a 184-inch cyclotron experiment on double charge exchange.

The characteristics of this readout have been reported in Nucl. Instr. Methods 33, 141 (1965), and at the APS January meeting in New York.

FINAL-STATE INTERACTION IN THE REACTION $He^3(d, t)2p$

H. E. Conzett, E. Shield, and R. J. Slobodrian

We have studied the reaction $He^3(d,t)2p$ in order to extract the effect of the proton-proton interaction in the final state from the cross-section data.[1]

Triton spectra were measured with an energy resolution of approximately 120 keV at deuteron energies of 24.7 and 33.4 MeV, at the 88-inch cyclotron. These spectra were obtained at laboratory-system angles of 6.75 and 8 deg, with angular resolution of 0.4 deg. The proton-proton final-state interaction appears as a strongly peaked distortion at the high-energy end of the triton spectrum.

We used the factored wave-function method[2,3] to extract the proton-proton scattering length from the data, and we obtained

$$a_{pp} = -7.7 \pm 1 \text{ F}.$$

This measurement serves as a quantitative test of spectrum distortion due to final-state interactions. Such a test is of great interest in the application of final-state interaction theory to extracting information on interactions that are not directly observable. Hence, we will attempt to obtain better statistical accuracy and energy resolution as a means of determining the quantitative limitations of the theory as applied to the above reaction.

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

Thomas Risser

The major decisions about design for the $\pi^- p \rightarrow \pi^0 n$ polarization experiment have been made, and much of the construction has been commenced.

Beam

The main elements of the beam have been decided upon. The pions will emerge from the snout near the north tangent tank and immediately undergo a 15-deg bend by a C magnet. This is followed by a quadrupole, a slit, an H magnet for further bending, and a second quadrupole. It then enters the blockhouse and encounters the target. At the position of the target the beam will have dimensions of 2 in. in the horizontal direction and 0.68 in. in the vertical, with a divergence of 13 mrad (3/4 deg). It will contain $\lesssim 0.3 \times 10^6$ pions/pulse. The momentum bite has not yet been fully determined, but is expected to be $\approx \pm 2\%$. The slit which is to achieve this is not yet designed.

Target

The target design is nearing completion. The plumbing and reservoir already exist. The final drawings on the design of the flask arrangement are forthcoming, and construction is expected to begin within a week.

γ Chambers

The first of the three identical sections has been completed and is being tested. The parts for the remaining two modules have been obtained, and they should be completed in several weeks at most (pending successful tests on the first module).

Neutron-Detection Target

The design has been completed except for three items: (a) the circulation of cold gas to uniformly cool the scintillator plates, (b) the machining of the light pipes, and (c) the physical mechanism for spacing the plates. Items (a) and (b) are progressing satisfactorily. The last item is waiting for the results of cold tests on the scintillator plates. They (the plates) are due May 10 and testing will begin immediately. All other parts are being made and should be completed by the end of May. Construction and testing should take an additional 3 weeks. The only difficulty expected is in bringing the scintillators down to

liquid hydrogen temperature. The special phototubes are ordered and due soon.

Neutron-Detection (Recoil Proton) Spark Chamber

The Lucite for the top and bottom plates is ordered, and machining of it should begin by the end of May. That job should take 3 to 4 weeks; assembly, another 6 weeks; and setting up and testing, several weeks. This fixes the earliest date for the beginning of the run at August 20. No other detail of the experiment will take this long to complete.

Optics

The optical system has been designed and the block-house design modified to accommodate it. The Lucite for the spark chamber lenses is ordered, and no delays in construction are expected. Of the two cameras we own, one is on loan to Crowe. We may need to procure another. The camera lenses are standard and available. The mirrors are not yet ordered but can be obtained in a hurry.

Electronics

The final form of signature has been decided on except for a few minor details. The electronics has been blocked out; it does not require any components which are not readily available from standard laboratory stockpiles. The one exception is three racks of 10 fast logic bins each. They are currently under construction and should be finished within 3 weeks. The test routine logic is nearly designed.

Counters

Once again, the general layout has been agreed upon but the details are only beginning to get attention. All major items of heavy equipment (such as the hydrogen target) have been modified to accommodate bases and light pipes. The number and positions of counters are now essentially fixed, but the actual design of shapes and sizes (and mounting) is only now commencing. No delays are envisioned, however.

PION-PROTON CHARGE-EXCHANGE EXPERIMENT

Charles B. Chiu

The Bevatron run for the pion-proton charge-exchange experiment was finished at the end of October 1963. The purpose of this experiment and its first-stage analysis work were summarized in previous reports. During the period of this report our film scan work was carried on satisfactorily. Last December an additional protractor measuring device was available to us which further speeded up the output of our measurements. By the end of March 1965 we had finished prescanning once through all the film in Berkeley, and measured all those frames of interest.

Since then scanners have been working on the following projects.

(a) They have been measuring those frames which were originally labeled a "charged-particle frame" by the prescanners--frames which had particle tracks with obvious charged-particle appearance coming from the target. Since our spark chambers were triggered on neutral final states, these frames with charged particles were only recorded and not measured. These amount to about 10% of the total frames. We are now taking a closer look at these frames.

(b) Scanners are also making various checks on their work, and they are also devoting some of their time to measuring those events which were deleted because of measuring errors, malfunction of the digitized protractor system, and other causes such as deficient tapes.

(c) We have also started scanning some of the film which was scanned by the Hawaii group with whom we are collaborating. It is estimated that this last stage of the scanning work should be completed by the early part of July.

During this period, the analysis work has continued. A quantitative study was made on the relationship between the uncertainty of the shower direction and its length. A length-dependent fiducial volume has been worked out to select the from-target events for analysis. The detection efficiency of our spark chamber is being studied with the aid of a Monte Carlo program. From experimentally observed one-shower and two-shower distributions, and the previously determined detection efficiency, together with this same program, the π^0 angular distribution can be determined. The validity of the latter can be checked by inputting this distribution to the program to see whether or not the predicted one-shower and two-shower distributions agree with the experimental results. Calculations have been done at two energies; the agreement in both cases is reasonable.

The corrections for single π^0 production ($\pi^- p \rightarrow \pi^0 \pi^0 n$) and double π^0 production ($\pi^- p \rightarrow \pi^0 \pi^0 \pi^0 n$) have also been considered. For single π^0 production, a phase-space distribution for the final three bodies, $\pi^0 \pi^0 n$, is assumed. Together with the determined detection efficiency of our spark chamber, the

background contribution is calculated with the aid of an existing three-body phase space program which Eandi used on his K_2^0 work. For the double π^0 production, from the presently available data, it is plausible to assume that most of the $\pi^0\pi^0\pi^0 n$ final state in our energy region is via the process $\pi^- p \rightarrow \eta^0 n \rightarrow 3\pi^0 n$. Since all three π^0's are identical and η^0 is a pseudoscalar meson, the $3\pi^0$ decay in the rest system of η^0 is governed according to phase space. With these conditions, a program has been written to give a quantitative estimate of the background correction due to this process. At present the branching ratios of $\pi^0 n$, $\pi^0\pi^0 n$, $\pi^0\pi^0\pi^0 n$ are being estimated from our existing data. Once these ratios are established, these two corrections will be essentially finished.

Two more points need to be considered before the results can be put in final form. First of all, it is well established that charge-exchange events do sometimes show up with three outgoing particles in the picture; i.e., two of them are γ rays from π^0 decay, and the third one is a proton knocked out from a Fe nucleus in the spark chamber by the recoiled neutron which has undergone the process $\pi^- p \rightarrow \pi^0 n$. If one of two gammas were missing, there would be only two outgoing particles in the picture, namely, one proton and one gamma, with a large opening angle between them. The correction for this type of event remains to be estimated. As mentioned earlier, there are charged particles in our pictures. Thus our final values of the total neutral cross sections can be determined only after a careful study of these measurements. The scanners are working on these measurements at present.

It is hoped that with some concentrated effort, the analysis work and the write-up of this experiment will be concluded within the next 2 to 3 months.

pC, pp, AND pn POLARIZATION AT ENERGIES FROM 310 TO 700 MeV

David Cheng, Burns Macdonald, and William Oliver

The experiment was described in the previous semiannual report. Data taking was completed in January 1965. Preliminary analysis of nucleon-nucleon polarization shows that it is a smooth function in energy. Our preliminary results are given in the following tables.

pC Polarization

θ_{lab} (deg)	Energy (MeV)				
	310	400	500	600	700
6	0.428 ± 0.004	0.394 ± 0.007	0.352 ± 0.005	0.294 ± 0.008	0.276 ± 0.008
8	0.509 ± 0.007			0.368 ± 0.016	0.364 ± 0.016
10	0.598 ± 0.007	0.518 ± 0.015	0.464 ± 0.013	0.421 ± 0.019	0.345 ± 0.017
12				0.491 ± 0.027	

pn Polarization

Energy (MeV)	$\theta_{c.m.}$	$P(\theta_{c.m.})$	Energy (MeV)	$\theta_{c.m.}$	$P(\theta_{c.m.})$
	32	0.462 ± 0.048		28	0.399 ± 0.029
	50	0.287 ± 0.026		45	0.269 ± 0.023
	67	0.093 ± 0.020		62	0.088 ± 0.025
310	85	-0.114 ± 0.024	600	79	-0.173 ± 0.030
	101	-0.239 ± 0.019		96	-0.332 ± 0.034
	118	-0.218 ± 0.016		113	-0.366 ± 0.033
	134	-0.179 ± 0.018		129	-0.256 ± 0.025
	150	-0.147 ± 0.040		146	-0.100 ± 0.025
	31	0.417 ± 0.035		27	0.311 ± 0.022
	49	0.252 ± 0.022		43	0.323 ± 0.167
	66	0.077 ± 0.022		60	0.162 ± 0.019
	84	-0.149 ± 0.025		77	-0.080 ± 0.024
400	100	-0.290 ± 0.024	700	94	-0.353 ± 0.026
	117	-0.263 ± 0.021		111	-0.414 ± 0.025
	133	-0.153 ± 0.018		128	-0.238 ± 0.019

pn Polarization (Contd.)

Energy (MeV)	$\theta_{c.m.}$	$P(\theta_{c.m.})$	Energy (MeV)	$\theta_{c.m.}$	$P(\theta_{c.m.})$
	149	-0.113 ± 0.029		145	-0.118 ± 0.016
	29	0.295 ± 0.022			
	47	0.254 ± 0.014			
	64	0.093 ± 0.016			
500	81	-0.155 ± 0.017			
	98	-0.264 ± 0.018			
	115	-0.268 ± 0.017			
	131	-0.142 ± 0.014			
	148	-0.112 ± 0.017			

pp Polarization

Energy (MeV)	$\theta_{c.m.}$	$P(\theta_{c.m.})$	Energy (MeV)	$\theta_{c.m.}$	$P(\theta_{c.m.})$
	30	0.401 ± 0.030		28	0.633 ± 0.037
	46	0.373 ± 0.007		34	0.552 ± 0.012
	50	0.363 ± 0.011		45	0.554 ± 0.008
	62	0.276 ± 0.007		51	0.519 ± 0.011
310	67	0.218 ± 0.008	600	62	0.430 ± 0.020
	79	0.116 ± 0.007		67	0.383 ± 0.041
	85	0.034 ± 0.009		79	0.179 ± 0.011
				84	0.119 ± 0.027
	31	0.430 ± 0.013		27	0.551 ± 0.015
	47	0.405 ± 0.007		35	0.519 ± 0.012
	49	0.407 ± 0.010		43	0.555 ± 0.016
	63	0.267 ± 0.008		52	0.509 ± 0.022
400	66	0.263 ± 0.009	700	60	0.471 ± 0.010
	80	0.100 ± 0.008		69	0.352 ± 0.039
	84	0.082 ± 0.008		77	0.252 ± 0.015
				86	0.110 ± 0.038
	29	0.496 ± 0.006			
	32	0.480 ± 0.011			
	47	0.451 ± 0.017			
500	49	0.443 ± 0.014			
	64	0.264 ± 0.010			
	65	0.308 ± 0.025			
	81	0.107 ± 0.015			
	82	0.111 ± 0.016			

$K_2^0 \rightarrow 2\pi^0$ EXPERIMENT FEASIBILITY STUDY

Richard D. Eandi

A preliminary study was made to ascertain whether a spark chamber system optimized for photon detection can efficiently and unambiguously identify the small CP-violating component of K_2^0 decay. The method of investigation consisted of postulating an experimental method and then performing the experiment on an IBM-7094 computer by generating events in a Monte Carlo fashion and observing the capability of the proposed experimental setup. Both CP-violating events, $K_2^0 \rightarrow 2\pi^0 \rightarrow 4$ photons, and events of the type $K_2^0 \rightarrow 3\pi^0 \rightarrow 6$ photons, of which only four photons are detected, were generated and sent into the detection system. The latter type of event is the major source of background.

With this procedure, a monoenergetic K_2^0 beam entering a cubical Pb-plate spark chamber array was judged desirable if not absolutely necessary. The details are described below.

A monoenergetic K_2^0 beam can be obtained by taking K^0's produced in the forward direction from the reaction $\pi^0 p \rightarrow \Lambda K^0$. Incident pions of 1030 MeV/c (just below Σ threshold) and

$$\frac{\Delta p_\pi}{p_\pi} \approx \pm 2\%$$

will produce a K^0 beam of momentum 615 MeV/c and

$$\frac{\Delta P_K}{P_K} \approx \pm 5\%.$$

With a meter-long liquid hydrogen target and a pion beam of intensity 10^6 pions per Bevatron pulse, 10^3 K_2^0 per Bevatron pulse per steradian is obtained at a position 5 meters downstream from the hydrogen target. If we construct a 1-m^3 cavity surrounded by photon-converting spark chambers (except for the K^0 entrance face of cube), and place this cubical spark chamber array behind a sweeping magnet 5 meters downstream from the hydrogen target, the number of K_2^0's decaying in this 1-m^3 cavity is ≈ 2 K_2^0/BeV pulse, or ≈ 1400 K_2^0/hr.

The spark chambers must be made of such a material as to give very good photon conversion efficiency. If one uses 35 1/25-in.-thick Pb plates in each spark chamber and requires at least three sparks as shower identification, then only 3% of the 600-MeV/c $K_2^0 \rightarrow 3\pi^0 \rightarrow 6\gamma$ will yield four converted photons, and more than 80% of 600-MeV/c $K_2^0 \rightarrow 2\pi^0 \rightarrow 4\gamma$ will yield four showers.

Since the accuracy of the determination of photon direction from showers was found to be much better than the accuracy of the determination of photon energies from showers, an event-reconstruction approach using principally direction measurements was applied. The $K_2^0 \rightarrow 2\pi^0$ event reconstruction was based on the circumstances that (a) the K_2^0 direction and momentum are known; (b) for two-body decay, the three momenta are coplanar and the vector sum of the two secondary π^0 momenta is zero in the K^0 c.m. system; (c) the opening-angle distribution for $\pi^0 \rightarrow 2\gamma$ in the K^0 c.m. system is such as to aid significantly in selecting the correct pairing of the four photons.

By using kinematic cutoffs on the angular correlation functions such as coplanarity, $\vec{P}_K \cdot (\vec{\pi}_1 \times \vec{\pi}_2)$, and collinearity, $(\vec{\pi}_1 \times \vec{\pi}_2)K^0_{c.m.s}$, which are consistent with experimental resolution one can separate and identify $K_2^0 \rightarrow 2\pi^0$ events from the background ($K_2^0 \rightarrow 3\pi^0 \rightarrow 4$ converted photons). However, in order to obtain good separability more than 80% of real $K_2^0 \rightarrow 2\pi^0$ events are rejected by the necessarily stringent kinematic cutoffs in the analysis program.

Thus, if a $(K_2^0 \rightarrow 2\pi^0)/(K_2^0 \rightarrow 3\pi^0)$ branching ratio of 1/300 is used, signal-to-background ratio of the order of 10:1 is attainable, with 20% of real $K_2^0 \rightarrow 2\pi^0$ events surviving the kinematic analysis program. If one reduces the momentum uncertainty from

$$\frac{\Delta P_K}{P_K} \approx \pm 5\% \text{ to } \pm 1\%$$

by using counter hodoscopes in the π^- beam, signal-to-background ratios of the same order with 35% real $K_2^0 \rightarrow 2\pi^0$ event-survival factor is attainable. If the $(K_2^0 \rightarrow 2\pi^0)/(K_2 \rightarrow \text{all})$ is 0.7×10^{-3} with a K_2^0 survival factor of 0.20 then the number of $K_2^0 \rightarrow 2\pi^0$ events seen per incident K_2^0 is 1.4×10^{-4}; for a survival factor of 0.35 it is 2.5×10^{-4}. Using the decay rate of 1400 K_2^0/h, one can obtain a data, collection rate of 0.20 event/h or 30 events per week (or 0.35 event/h and 50 events per week). The experiment appears feasible with the above method.

PHYSICS RESEARCH

William A. Nierenberg in charge

ATOMIC BEAM GROUP

Howard A. Shugart

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

The techniques employed in this research include various atomic beam methods as well as a variety of optical pumping 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 momenta, and g_J factors. The advantages of beam techniques in obtaining these quantities rests in their conceptual simplicity and sensitivity, and in the ease of interpretation of results. The measurements comprise important test information for theories of the nuclear ground state. In addition, information on the electronic structure of atoms both from beam experiments and from optical pumping experiments is useful in evaluating theories of atomic structure.

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

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3. Tetsuo Hadeishi, Orilla A. McHarris, and William A. Nierenberg, Radio-frequency Resonance of the Metastable State $(2, {}^2P_{3/2} \rightarrow 3, {}^2S_{1/2})$ of Neon Produced and Aligned by Electron Impact, UCRL-11825, Dec. 1964.

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PHYSICS RESEARCH

Wilson M. Powell and Robert W. Birge in charge

ANALYSIS OF THE DECAY $K^+ \rightarrow \pi^0 + \mu^+ + \nu$

Section I: Muon Kinetic Energy Spectrum in $K^+_{\mu 3}$ Decay

Wilson M. Powell and Carl L. Sandler

In studying T_μ, the muon kinetic energy spectrum in $K^+ \rightarrow \pi^0 \mu^+ \nu$, we have obtained information on time reversal, the form factor ratio ($\xi = f_-/f_+$), and the branching ratio, $BR_{K_{\mu 3}}$. Our preliminary results on the form factor ratio and the branching ratio for $K^+_{\mu 3}$ decay were reported at the December 1964 APS meeting at Berkeley.[1] Assuming ξ is a real number, with $42 \leq T_\mu\,(\text{MeV}) \leq 94$, we find, for 941 events, Re $\xi = -0.5^{+0.7}_{-0.9}$ and $BR_{K_{\mu 3}} = (2.9 \pm 0.2)\%$. To investigate time-reversal invariance in this decay we have done a maximum-likelihood analysis of these same data, assuming ξ is a complex number. We find Re $\xi = 0^{+1.9}_{-1.2}$ and Im $\xi = 0 \pm 1.4$. These results were reported along with other work in a postdeadline paper at the April 1965 APS meeting in Washinton, D. C. The final results of our studies are being prepared for publication.

Section II: Determination of Re ξ and Im ξ by Fitting the Dalitz Plot of T_μ vs T_π

George Gidal, George E. Kalmus, and Robert T. Pu

A total of 444 events was found in which the γ rays from the π^0 converted and the μ^+ stopped in the chamber, and which satisfied the conditions

(a) $40 < T_\mu < 90$ MeV,
(b) $0 < T_{\pi^0} < 110$ MeV.

These events were plotted on a Dalitz plot and the population density was compared, by means of a two-parameter maximum-likelihood method, with that predicted for different values of Re ξ and Im ξ. Preliminary results were reported at a postdeadline paper at the April 1965 APS meeting in Washington, D. C.

Section III: Determination of the Polarization of the μ

George Gidal, George E. Kalmus, and Robert T. Pu

This work uses essentially the same events as Section II except that the μ energy cuts have been slightly relaxed. The work was done in two parts:

(a) Direct measurement of the component of the polarization of the μ normal to the π-μ decay plane.

The method used is described in the preceding semiannual report. Preliminary results were presented at the 1965 New York APS meeting. On the basis of a total of 691 events; we obtain

$$P\,\frac{1}{\mu} = +0.04 \pm 0.35 \left[P\,\frac{1}{\mu} = \sigma_\mu \cdot (\hat{P}_\pi \times \hat{P}_\mu)\right].$$

(b) Analysis of the total polarization of the μ as a function of Re ξ and Im ξ.

By means of a two-parameter maximum-likelihood program, the direction of the μ polarization is compared with the values predicted for different values of Re ξ and Im ξ. Final analysis of this is in progress.

This work is a collaboration with the Fry-Camerini-March group at the University of Wisconsin.

K^-p INTERACTIONS FROM 825 TO 1150 MeV/c

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

We are continuing to analyze the K^-p exposure in the 25-inch hydrogen bubble chamber and, to date, we have scanned and measured 13 000 K^-p elastic scatterings, 25 000 events with a "V" in the final state, and about 3 000 events with a Σ in the final state. The measurements have been made, for the most part, on the FSD system with the exception of the Σ's, the short track of which makes automatic measurement difficult.

Preliminary results were presented in an invited paper at the American Physical Society meeting at Berkeley, California, in December 1964 by one of the authors (Robert P. Ely). These results included a determination of the branching ratio of the 1815 Y_0^* resonance into the $Y^*(1385) + \pi$ channel, and some evidence in the charge-exchange angular distributions for the proposed $Y^*(1765)$.

EXPERIMENTAL STUDY OF K_{e4} DECAY

Powell-Birge Group

The rare K_{e4} decay modes $\pi^+\pi^-e^+\nu$, $\pi^+\pi^+e^-\bar{\nu}$, and $\pi^+\pi^+\mu^-\bar{\nu}$ have been searched for in a sample of approximately 3×10^6 K^+ decays. A total of 69 events of the mode $\pi^+\pi^-e^+\nu$ were observed. The other two modes are forbidden by the $\Delta S = \Delta Q$ rule and no examples were found. This experiment gives an upper limit on the amplitude ratio $X = A(\Delta S = -\Delta Q)/A(\Delta S = \Delta Q)$ for the axial vector current of 0.25, assuming no final-state $\pi\pi$ interaction. The effects of final-state interactions in the $\pi\pi$ system modify the interpretation of results, and may be large. The rate for the $\pi^+\pi^-e^+\nu$ mode was determined to be $(2.9 \pm 0.6)\times10^3$ sec^{-1}. The angular correlations between the planes formed by the lepton pair and the pion pair, and the angular distribution of π^+ with respect to the dipion line of flight in the dipion rest system for the 69 events have been studied. The dipion mass spectrum is presented for the 69 $\pi^+\pi^-e^+\nu$ events. The value of the ratio of the two form factors in K_{e4} decay (p wave to s wave) was found to be $\eta = 0.8 \pm 0.30$ from an analysis of these correlations. An estimate of the low energy $\pi\pi$ phase shift was determined to be $|\delta_0 - \delta_1| = 35° \pm 30°$ from the angular correlations and the $\pi\pi$ invariant mass spectrum. $|\delta_0 - \delta_1|$ is the difference between the s wave (δ_0) and p wave (δ_1) phase shift averaged over the $\pi\pi$ invariant mass spectrum. Since this spectrum is peaked at low dipion invariant mass, this average pertains mainly to an invariant mass in the region of 179.2 to 350 MeV. The shape of the dipion invariant mass spectrum is not in agreement with the shape expected if a σ resonance exists and has a mass approximately 400 MeV with a width approximately 100 MeV.

The analysis of this experiment is now complete and the above results have been published in UCRL-16083 and have been submitted to the Physical Review.

Σ-π RESONANCES

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

To verify the existence of the T = 2 Σ - π resonance with a mass of 1425 MeV and the $Y_1^*(1765)$, we are studying the reactions

$$K^- + D \rightarrow \Sigma^- + \pi^- + \pi^+ + (P)$$
$$K^- + D \rightarrow \Sigma^+ + \pi^- + \pi^- + (P)$$

with 950 MeV/c, 1050 MeV/c and 1150 MeV/c K^- in the 25-inch chamber. Scanning and measuring are in progress for the 1050 MeV/c and 1150 MeV/c data. Final analysis of the data at 950 MeV/c is in progress.

SIGMA-HYPERON PRODUCTION

Robert Bell, Robert W. Birge and Yu-Li Pan

We are measuring the cross section for production and polarization of sigma hyperons from K^-p reactions at seven momenta. The momentum ranges from 850 to 1150 MeV/c. Scanning and measuring is in progress.

K^-n INTERACTIONS AT 915 AND 1015 MeV/c

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

We are investigating the reactions

$$K^-n \rightarrow \Lambda\pi^- , \quad (1)$$
$$K^-n \rightarrow \Lambda\pi^-\pi^0 , \quad (2)$$

at beam momentums of 915 and 1015 MeV/c. A total of 75 000 pictures at 915 MeV/c and 63 000 pictures at 1015 MeV/c have been taken in the LRL 25-inch deuterium bubble chamber at an average intensity of 12 K^- per picture. The purpose of the experiment is to study K^-n reactions and, in particular, to investigate the properties of the Y_1^* resonance at 1765 MeV.

To date 75% of the 915-MeV/c film and 60% of the 1015-MeV/c film has been measured and analyzed, giving a total of 6000 events (1) and (2) at 915 MeV/c and 4000 events (1) and (2) at 1015 MeV/c.

Preliminary data in the angular distributions and polarizations of the above inelastic K^-n channels is consistent with $J = 5/2^-$ Y_1^* resonance around 1760 MeV/c. These preliminary results have been presented at the Washington meeting of APS, April 28, 1965.

MASS AND WIDTH DIFFERENCES FOR N^{*-}-N^{*++}

Anne Kernan and Sedong Kim

This experiment has been completed. The values for the mass and width differences for N^* in the $3/2^+$ decuplet are 7.9 ± 3.9 MeV and 24.7 ± 14.2 MeV. The result will be submitted to the Physical Review.

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 350 events which fit the hypothesis

$$K^+ \rightarrow \pi^0\, e^+\, \nu$$
$$\qquad\quad \hookrightarrow 2\gamma \rightarrow 2(e^+e^-) .$$

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.

The spectra of the decay products are consistent with a pure vector interaction, and are predicted by the V-A theory. We find that the energy dependence of the form factor in K_{e3} decay is

$$f_+ \propto 1 + (0.08 \pm 0.03)\, q^2/M_{\pi 2}\,,$$

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

A preliminary report on this work (UCRL-11553) was submitted to the 1964 International Conference on High Energy Physics, Dubna.[1] Additional events are being measured and the analysis of the data continues.

This work is being done in collaboration with Ugo Camerini at the University of Wisconsin and Cyril Henderson at University College London, England.

π^-p INTERACTIONS AT 3.9 BeV/c

Robert W. Birge, Robert P. Ely, and Thomas G. Schumann

We have investigated the production of π-π and π-nucleon resonances or enhancements with a 3.9-BeV/c π^- beam in the 72-inch hydrogen bubble chamber.

DATA REDUCTION

Robert W. Birge and P. Wesley Weber

With a total of 20 (full-time equivalent) visual measurement personnel, the following data reduction was accomplished in the past six months:

Scanning

Experiment	Bubble chamber	Beam	Number of frames
Conventional system			
28	30-inch Freon	4.5-MeV/c K^+, stopping	22 580
29	20-inch deuterium (Brookhaven)	3.69-BeV/c deuteron	19 035
32	25-inch hydrogen	850- to 1150-MeV/c K^-	191 846
34	25-inch deuterium	850- to 1150-MeV/c K^-	242 441
		Subtotal	475 902
FSD system			
32	25-inch hydrogen	850- to 1150-MeV/c K^-	78 661
34	25-inch deuterium	850- to 1150-MeV/c K^-	33 944
		Subtotal	112 605
		Total	588 507

Measuring

Equipment	Measuring hours	Number of vertices	vertices per measuring hour	Measuring hours per 4032 hours
Microscope C	1971.9	11 023	5.6	0.45
Microscope E	2 300.6	12 850	5.6	0.53
MP-1C	2 116.9	12 097	5.7	0.48
Total	6 389.4	35 970	5.6	0.49

1. C. L. Sandler and W. M. Powell, "Ratio of the Form Factors in $K^+_{\mu 3}$ Decay," Bull. Am. Phys. Soc. 9, 722 (1964).

PHYSICS RESEARCH

Emilio Segrè and Owen Chamberlain in charge

INTRINSIC RELATIVE PARITY OF THE K-Σ-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, begun in September 1964 and completed in January 1965, consisted of scattering π^+ mesons at 1150 MeV/c from the protons of a polarized hydrogen target, and measuring the asymmetry in the production of the final state $K^+ + \Sigma^+$. The algebraic sign of this asymmetry directly gives the K-Σ-N parity.

This was the first experiment done with a polarized target in which strange particles were produced. A special experimental problem was introduced by the fact that the Σ^+ was too short-lived to be detected. Therefore, the correlation of energy and production angle of the K^+ was used to identify the production events from hydrogen. Analysis of the spark chamber pictures is currently in progress. A total of 50 000 pictures was taken, of which about 15 000 will be measured, and 1500 are expected to be free proton events.

As a by-product of the experiment, we expect to obtain the Σ^+ polarization as a function of angle to greater accuracy than has heretofore been achieved at this energy.

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

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

After the successful completion of the above experiment, we made a brief run on the similar experiment using an 1150 MeV/c π^- beam (instead of π^+), to measure the Σ^- polarization. Since the Σ^- does not reveal its polarization by an asymmetry in its decay, the polarization can be measured only with a polarized target. A total of 15 000 pictures was taken. Analysis awaits completion of the analysis of the K-Σ-N parity experiment.

POLARIZATION IN π^--p ELASTIC SCATTERING FROM 150 TO 450 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

As part of a program to determine the detailed aspects of the low-energy π-nucleon interaction, scintillation counter hodoscopes are being used to detect the polar and azimuthal angles of both the scattered π^- and the recoil protons. The experiment, using the polarized target, is being carried out at the 184-inch synchrocyclotron. The π^- beam is variable in energy from 150 to 450 MeV, an energy spread several times as great as had been previously obtained, so that data can be taken at many energies without changing the setup. Data can be simultaneously collected at about 35 polar scattering angles, and the solid angle included at each polar angle has been quadrupled from that of our former counter system.

A new system for data collection and handling has been developed to cope with the increased amount of data. At its core is a PDP-5 computer, used on-line, which collects, sorts, and stores the data, and displays selected parts of it on an oscilloscope screen for the experimenters' benefit. Detailed data analysis is still done on the IBM 7094 computer.

The run may be completed about June 30, 1965.

POLARIZED TARGET DEVELOPMENT

Owen Chamberlain, Claude H. Schultz, and Gilbert Shapiro

The installation of two 1000-cfm Roots booster pumps in the helium refrigeration system has increased the typical target polarization from 45% to an estimated 60%.

A number of improvements have been

made in the polarization detection apparatus to increase the accuracy of the polarization measurement. These include raising the rf amplifier gain (to allow the apparatus to operate with lower rf amplitude on the initial tuned circuit and hence less depolarization in the measuring process), installation of several devices to monitor the gain stability of the detection system, and installation of a McLeod vacuum gauge to measure accurately the temperature of the liquid helium bath.

PROTON-PROTON INTERACTIONS AT 6 BeV/c

W. Chinowsky, Jonas Schultz, Stanley L. Klein, and Robert R. Kinsey

An experiment to study p-p inelastic interactions in the 72-inch bubble chamber was started in late April and is being continued. To date approximately 120 000 photographs, with an average of 12 incident particles per pulse, have been obtained. A substantial improvement in efficiency and stability of operation has been obtained by pulsing off the electric field on a standard 15-ft-long 4-in.-gap electromagnetic spectrometer. The magnetic field on the spectrometer then deflects the beam vertically off the final slit in the system. In this way it has been possible to independently control the beam intensity to within ± 1 incident beam track per picture.

Scanning and measuring are in progress. Based on some ten rolls scanned (about 7000 photos) we find inelastic events at a rate of approximately one per two pictures; strange particles occur in about 2% of these. Measuring is in progress with both the Franckenstein and the FSD-Roadmaker measuring machines.

K^+p INTERACTIONS AT 2.7 BeV/c

Riley D. Newman, W. Chinowsky, and Jonas Schultz

Analysis is nearing completion on a 2.7-BeV/c K^+p bubble chamber experiment described in the preceding report. Rescanning and measuring are complete, and all events have been kinematically analyzed. The production of $K^*(890)$ or $N^*(1238)$ (or both) is found to dominate the inelastic reactions, and is being studied in terms of a peripheral model modified by absorption. In the case of a K^* produced with an N^*, the K^* decay distribution in its rest frame, if the incident K direction is taken as the z axis, is proportional to $\cos^2\theta$ and close to isotropic in ϕ, suggesting that single π exchange accounts adequately for $K^+p \rightarrow K^*N^*$. Possible evidence for a $\kappa(725)$, but none for a $K\pi\pi$ resonance at 1175 MeV, is found in a partial sample of the data. The six events in which associated production of a K and a hyperon takes place are too few to provide evidence for possible S = +2 resonances.

LOW-ENERGY HYPERON-PROTON INTERACTIONS

W. Chinowsky, Robert R. Kinsey, Walter N. Rybicki, and Jonas Schultz

Scanning, measuring, and most of the analysis are presently complete in an experiment to investigate the interactions of Σ hyperons and protons at 5 to 10 MeV laboratory-system kinetic energy. A total of 4700 events has been measured, yielding the following numbers of useful events in the reactions of interest:

$\Sigma^+p \rightarrow \Sigma^+p$	26 events
$\Sigma^-p \rightarrow \Sigma^-p$	58 events
$\Sigma^-p \rightarrow \Sigma^0n$	59 events
$\Sigma^-p \rightarrow \Lambda^0n$	86 events
$\Sigma^-p \rightarrow \begin{Bmatrix}\Lambda^0n\\ \Sigma^0n\end{Bmatrix}$	(at rest) ≈ 3000 events.

Cross sections as functions of momentum have been determined for the in-flight events, as well as the branching ratio for the at-rest reaction. The results are in rough agreement with predictions based on the assumption of global symmetry for the pion-baryon coupling constants. More extensive theoretical analysis must be done to compare the results with predictions of the higher-symmetry models. Articles are being prepared for publication. (This work was covered in UCRL-11918 Abstract, submitted to the American Physical Society for the meeting in Washington, D. C., April 1965.)

RADIATIVE PION DECAY

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

Some preliminary work on an experiment to measure the decay, $\pi^+ \rightarrow \mu^+ + \nu + \gamma$, has been started at the 184-inch cyclotron.

TEST OF TIME-REVERSAL INVARIANCE IN $K^+ \rightarrow \pi^0 + \mu^+ + \nu$

David Cutts, Tommy Elioff, Rae F. Stiening, and Clyde E. Wiegand

An apparatus to detect an asymmetry of the form $\sigma_\mu \cdot p_\pi \times p_\mu$ in the $K_{\mu 3}$ decay mode is in the final stages of construction. It is expected that approximately 300 000 spark

chamber photographs will be taken, and that in this sample there will be 5000 complete events of the above type. The SPASS computer scanning system at MIT will be used in the film analysis.

PHYSICS RESEARCH

George H. Trilling and Gerson Goldhaber in charge

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

K^+d INTERACTION AT 2.3 BeV/c

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

From an unbiased sample the following cross sections were obtained:

Product	Cross-section mass
K^0pp	1.41 ± 0.2
$K^0\pi^0pp$	3.16 ± 0.46
$K^0\pi^+p(n)$	3.2 ± 0.25
$K^0\pi^+(p)$	1.96 ± 0.16
$K^+\pi^-pp$	3.06 ± 0.15
$K^+\pi^-\pi^+pp$	1.08 ± 0.14
$K^+\pi^+\pi^-p(n)$	1.86 ± 0.11
$K^+\pi^+\pi^-n(p)$	1.16 ± 0.07
$K^0\pi^+\pi^-pp$	0.75 ± 0.9

The errors quoted are statistical and do not include a 10% normalization error. In a comparison of K^{*0} production in the reaction $K^+d \to K^{*0}p(p)$ (pure isovector exchange) with K^{*+} production in the reaction $K^+d \to K^{*+}p(p)$ [iso and isoscalar exchange] the following components for the K^* decay spin density matrix were found for momentum transfer less than 20 m_π^2:

	ρ_{00}	ρ_{1-1}	Re ρ_{10}
K^{*0}	$0.6 \pm^{0.03}_{0.05}$	$-\left(0.069^{+0.07}_{-0.05}\right)$	-0.215±0.03
K^{*+}	$0.15^{+0.1}_{-0.15}$	$-\left(0.01^{+0.07}_{-0.12}\right)$	-0.1± 0.06

The reactions $K^+d \to K^{*+}d$ and $K^+d \to K^{*0}\pi^+d$ were observed. The former is explicable in terms of coherent production on the deuteron. The latter seems rather to involve an exchange process in which the K^* is produced at one vertex and the $(d\pi)$ system at the other. At the present level of statistics no $d\pi$ resonant state is evident.

CURRENT STATUS OF K25 K^+p EXPERIMENT

The analysis of data obtained in an exposure of the Lawrence Radiation Laboratory 25-inch bubble chamber to a separated K^+ beam has been continued. Some 10 000 K^+p events at 960 MeV/c incident K^+ momentum have been measured, and of these just over 1800 are inelastic single-pion-production events. These events are dominated by $N^*(3/2, 3/2)$ production, although some K^* production below threshold is present.

The production and decay angular distributions of the $N^*(3/2, 3/2)$ are consistent with a single ρ-meson exchange mechanism dominated by a magnetic dipole coupling without modification due to form factors or absorption effects. The final analysis of the data is in progress.

At 1200 MeV/c incident K^+ momentum, first measurements are complete on a sample of approximately 10 000 events, and a preliminary analysis is in progress.

At 1600 MeV/c, some 700 events of the type $K^+p \to K^0p\,\pi^+ \to (\pi^+\pi^-)p\,\pi^+$ have been measured. Both $N^*(3/2, 3/2)$ and K^* production are important channels, and details of the production mechanisms are being studied.

K_2^0 INTERACTIONS AND DECAY

During the period after September 1964, a substantial effort was devoted to the design and preparations of a high-intensity K^+ beam, which is currently in use for the study of K^0 interactions and decays in the 25-inch hydrogen bubble chamber. The beam was designed to operate over a momentum range of 600 to 1000 MeV/c, and uses a single 10-foot electrostatic separator. The design indicated a total momentum bite of 5%, and solid angle of about 2.5 millisteradians. At an operating momentum of about 830 MeV/c, an approximate flux measurement seemed to be in substantial agreement with that expected from the design.

The K^0 particles are produced by K^+ charge exchange in a small platinum target

located about 20-in. from the center of the bubble chamber. The beam is allowed to pass beside the chamber, where the K^+ strikes the target. The π^+ and protons, which are spatially separated from the K^+, miss the target, and pass by. The K_2^0, which are produced at about 90 deg to the incident K^+ direction, enter the chamber sensitive volume through thin windows, accompanied by a few background particles per picture. A K_2^0 event occurs about every 20 pictures, and a total of several thousand events is expected. K_1^0 particles that originate in the target do not live long enough to enter the chamber, since the average K^0 momentum is about 300 MeV/c. The K_2^0 decays are being studied to make more precise determinations of decay angular and momentum distributions, branching ratios, and decay rates. K^0 and $\overline{K}^0$ cross sections will be determined for the various interaction channels.

DATA HANDLING

Howard S. White in Charge

COMPUTER PROGRAM DEVELOPMENT

HAZE

The main HAZE program (420) was modified to handle film from the 80-inch BNL hydrogen chamber. This included the re-evaluation of filtering and ionization parameters and new fiducial positions, as well as well as the ability to measure BNL film format. Program 420 was also modified and reassembled to operate under the TRIST executive program. Debugging of these changes was completed and routine production status was achieved.

A program was written (432) to merge the three HAZE output tapes onto one library tape. The basic format consists of one record per event containing data for all three views. Another program (436), which merges tapes in this new format, was also written and debugged. The implementation of these programs will substantially reduce the tape storage space now required for HAZE libraries.

A program (437) which can read a FAIR output tape and produce a corresponding HAZE library was also written and debugged. This program has proved quite useful in the analysis of low-frequency errors.

A clean-up assembly was done on the scan-table editing program (422). Modifications were made to handle BNL 80-inch chamber film, and constants were added for processing several new experiments.

Flow charts were made for a program (431) to check the fidelity of the FSD output and to assist in the diagnosis of FSD hardware failures. This program will detect and summarize all data departures. These include conspicuous solid errors--that is, those due to component destruction--intermittent errors caused by occasional component failure, and any system failure such as word format or word sequencing.

Work was also begun on a calibration program which will allow more flexibility in mechanical changes to the FSD, as well as provide a further diagnostic tool in FSD checkout.

(Joan Stekler, Joyce Crawford, Jack Cockrill, Carol Osborne, and Loren Shalz)

FOG

Most of the FOG programs are now running under the TRIST executive monitor system. Generally, this was accomplished by modification to the existing code. However, program 123, the Assignment Request Tape generator, required a new assembly.

Additional tests on the microscope data were put into program 137A, and the off-line error report was made more useful by flagging the records that need special attention.

Program 135B, the FSD geometry program, was modified in several areas. It can now operate on some new forms of input, (a) the new HAZE library format, and (b) a FAIR selection tape run against HAZE input. Two new tests were added to 135B; one is a test requiring that the calculated vertex point be no farther away from the first measured point on any track than one-third the chord length of that track. The other new test limits the length over which a local fit to a circle can be used to extrapolate one view into the other. Beyond a given film tolerance the circle is found from the first, middle, and last points on the track. A summary, by roll number, of events processed was added to the program and has aided in the analysis of runs. The ability to start at a particular picture number has also proven useful in debug runs.

Optical and magnetic field constants for the BNL 80-inch chamber were derived, and preparation was begun for the changes in the optics and magnetic field of the 72-inch chamber.

For these chambers, and for all future experiments, a new routine in 135B, which performs a least-squares fit on n fiducial measurements, was written. Since the time required for the FSD to measure a picture is constant, measuring all the fiducials in a picture is as economical as measuring one. This feature provides a substantial improvement in accuracy at no extra cost.

(Shirley Buckman and John Gotthelfsman)

CLOUDY

All CLOUDY programs, except the merge program, were modified to run under the TRIST monitor.

The CLOUDY abstraction program (208) was reassembled and partially debugged, with extensive changes to the mass permuting section.

Two new momentum-editing subroutines were written and debugged for the kinematics program (209). One provides for up to 28 changes of beam momentum within an experiment, and the other allows the beam track (momentum, dip, and azimuth) to be computed from the x y z position of the vertex point and a table of nominal beam values. A conditioning matrix was added to the constraints portion of program 209 which minimizes the effect of round-off in computing the propagated error matrix.

Work was begun on a disk-utilization feature in program 209 which will eliminate the requirement of multiple passes and greatly improve the running time for complicated event types.

Parameters for several new experiments were also derived and implemented in the CLOUDY programs.

(Vivian Morgan, John Gotthelfsman, and Frank Windorski)

FAIR

All FAIR programs were successfully modified to operate under the TRIST executive monitor, and debugging of a FAIR library merge program (311) was nearly completed.

A substantial number of special-purpose calculations was written, including polarization angle and momentum transfer.

The ability to automatically generate AR input to FOG for events satisfying any desired level was also added.

(Loren Shalz)

DAPR

Program 504 (track following) was revised for more programming flexibility and increased track-following speed. The beam and nonbeam sections were interwoven so that various subroutines are now shared. New nonbeam track-following methods have been adopted, to enhance the speed of the program without affecting the results.

Program 506 (formerly just track linking) was extended to search for fiducials and vertices. Short, straight tracks at an angle near 45 deg are selected as potential fiducial arms. Pairs of these tracks are tested for crossing and the intersection of each pair of crossing arms is computed. This may be used to search for fiducials over the entire picture, or to search only near specified points.

Vertices are detected by looking for tracks that end near each other and can be extended to a roughly common point. This rough point is saved as the approximate location of the vertex. A "vertex list" is made which includes, for each vertex, the location, the tracks involved, and pointers to related vertices in the event. Fiducial and vertex searching have both been remarkably successful.

Also, a section has been added to program 506 to make a Cal-Comp plot of a picture after all track linking is completed.

(Charles Dickens and Mary Downton)

TRIST

Debugging of the three-level priority executive monitor system (TRIST) was completed for "A" and "C" levels operating simultaneously. All HAZE production is now run routinely as A level, with background production and debug runs as C level. Work is now in progress to facilitate running B-level programs. Thus the principal objective of making maximum use of the available main-frame time during FSD runs was accomplished.

TRIST now produces data for a time-accounting program, and work was begun on a program (52) which will provide a breakdown of computer usage by account number, run type (production, debug, etc.), program number, and experiment or Assignment Request. Summaries will be produced, for any given time period, of the number of runs, amount of used time, and number of new chains where appropriate.

(Joan Stekler, Robert Larson, and Carol Osborne)

DATA PROCESSING OPERATIONS

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

Event measurements analyzed

Chamber	Beam	Experimental group	Number of events
Franckenstein operation			
30-inch Freon-propane	Stopping K^+	Powell-Birge	720
20-inch Deuterium	3.7-BeV/c D	Powell-Birge	489
25-inch Hydrogen	0.850—1.150-BeV/c K^-	Powell-Birge	9 136
25-inch Deuterium	0.850—1.150-BeV/c K^-	Powell-Birge	9 646
			19 991
FSD Operations			
25-inch Hydrogen	0.850—1.150-BeV/c K^-	Powell-Birge	26 220
25-inch Deuterium	0.850—1.150-BeV/c K^-	Powell-Birge	14 566
25-inch Hydrogen	0.850—1.600-BeV/c K^+	Trilling-Goldhaber	25 146
			65 932
		Total events analyzed	85 923

ACCELERATOR OPERATION AND DEVELOPMENT

ACCELERATOR STUDY GROUP

Edward J. Lofgren in charge

The work of the Accelerator Study Group has been published in summary form in the Interim Report of December 1964, and will be described in detail in the 200 BeV Accelerator Design Study to be published about July 1, 1965.

BEVATRON

Edward J. Lofgren in charge

Reports on Bevatron Operation and Development are issued on a quarterly basis. Reports UCRL-16203 and -6204 cover the period October 1964 through March 1965.

184-INCH CYCLOTRON

Robert L. Thornton in charge

Reported by James T. Vale

Material for this section had not been received at the time the report was issued.

88-INCH CYCLOTRON

Homer E. Conzett in charge

OPERATION

The distribution of cyclotron time during the period November 1964 through April 1965 was:

	8-hr shifts	%
Nuclear reactions and scattering research	267	54
Biomedical research	19	4
Cyclotron research	49	10
Isotope production	110	22
Preventive maintenance and scheduled shutdowns	39	8
Repairs (unscheduled shutdown)	10	2
	494	100

Remote vertical positioning of the tungsten septum, slight changes in its shape, and continuous television monitoring of the heat distribution on the septum have permitted a factor-of-three increase in external beam.

CYCLOTRON RESEARCH AND DEVELOPMENT

The regenerative-deflection system design and fabrication have continued, and installation is scheduled for the Summer of 1965. A new dee is being designed and constructed.

A mock-up has been made of the system for providing axial injection of ions. Ion-beam transport will be studied under conditions which simulate actual injection into the cyclotron.

Development of new beams continued. Third harmonic acceleration of low-energy He^4 and He^3 beams was achieved.

Installation of new trim-coil power supplies was completed. This will permit separate control of all seventeen trim coils. Design and fabrication have begun on a system that will automatically set the proper trim-coil currents for the many different beam energies and particles available.

EXPERIMENTAL RESEARCH

Beams of protons, deuterons, He^3, He^4, and polarized protons at various energies have been provided for a large variety of experiments in nuclear reactions, scattering, and fission research. Detailed reports describing experimental results are contained in the current Chemistry Division Annual Report.

ELECTRON LINEAR ACCELERATOR

Edward J. Lofgren in charge

Material for this section had not been received at the time the report was issued.