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PHYSICS DIVISION SEMIANNUAL REPORT

May 1962 through October 1962

Berkeley, California

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GENERAL PHYSICS RESEARCH

PHYSICS RESEARCH

Luis W. Alvarez in charge

RESEARCH WITH BUBBLE CHAMBERS

The work reported below has been done—as indicated at the end of each subsection—by Gideon Alexander (GA), Margaret H. Alston (MHA), Luis W. Alvarez (LWA), Jared A. Anderson (JAA), Angela Barbaro-Galtieri (AB-G), Pierre Bastien (PB), J. Peter Berge (JPB), Bevalyn B. Crawford (BBC), Frank S. Crawford, Jr. (FSC), Orin I. Dahl (OID), Massimiliano Ferro-Luzzi (MF-L), Robert L. Golden (RLG), Ronald A. Grossman (RAG), J. Richard Hubbard (JRH), William E. Humphrey (WEH), Darrell O. Huwe (DOH), Laurance D. Jacobs (LDJ), George R. Kalbfleisch (GRK), Janos Kirz (JK), Lester J. Lloyd (LJL), Gerald A. Lynch (GAL), Gerald Meisner (GM), Joseph J. Murray (JJM), LeRoy R. Price (LRP), Alan Rittenberg (AR), Arthur H. Rosenfeld (AHR), Ronald R. Ross (RRR), Joseph A. Schwartz (JAS), Janice Button Shafer (JBS), Gerald A. Smith (GAS), Frank T. Solmitz (FTS), M. Lynn Stevenson (MLS), Harold K. Ticho (HKT), Robert D. Tripp (RDT), Mason B. Watson (MBW), Charles G. Wohl (CGW), Stanley G. Wojcicki (SGW), and David Young (DY).

The K72, π 72 Experiment (72-Inch Chamber)

General Information

The group terminated the K72, π 72 run at the Bevatron in early June 1962 after extended use of the separated high-energy K^- beam in the 72-inch liquid hydrogen bubble chamber over a period starting in September 1961. The following film was obtained:

(a) K^- on hydrogen--789 rolls at nominal momenta of 1.03, 1.09, 1.22, 1.34, 1.45, 1.51, 1.63, 1.73, 1.82, and 1.97 BeV/c.

(b) K^- on deuterium--47 rolls at nominal momenta of 1.05, 1.13, and 1.51 BeV/c. The total K^- exposure corresponds to approximately 13,000 MBE's (1-mb-equivalent events). The hydrogen film at 1.82 and 1.97 BeV/c is currently being analyzed by the UCLA group.

(c) High-energy π^- on hydrogen--453 rolls at nominal momenta of 1.51, 1.69, 1.89, 2.05, 2.17, 2.25, and 2.36 BeV/c.

(d) High-energy π^- on deuterium--58 rolls at 2.28 BeV/c. The total high-energy π^- exposure corresponds to approximately 15,000 MBE's.

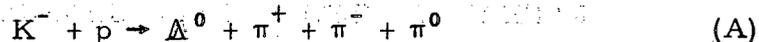
(e) Low-energy π^- on hydrogen--60 rolls at 0.520, 0.570, 0.602, 0.670, 0.722, 0.800, and 0.850 BeV/c.

(f) Low-energy π^\pm on deuterium--6 rolls at 0.765 BeV/c. The total low-energy π^\pm exposure corresponds to approximately 2,000 MBE's. All pion film was obtained on a "parasitic" basis with other experiments during periods not used for K^- .

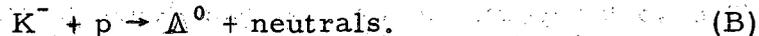
Essentially all the film has been scanned the first time. The first measurements are approximately 33%, 90%, and 100% completed for the K^- , high-energy π^- , and low-energy π^\pm experiments, respectively. Present results of the various experiments from the $K72, \pi72$ complex plus other current experiments are given below.

Study of $K^- + p \rightarrow \Lambda^0 + \omega^0, \Lambda^0 + \eta^0$ at 1.51 BeV/c

Analysis has continued at 1.51 BeV/c of the reactions



and



Approximately 1350 events of type (A) and 4000 events of type (B) have been found in 40,000 pictures. About 50% of all events in the former class are of the type $K^- + p \rightarrow \Lambda^0 + \omega^0$, with the ω^0 subsequently decaying through its predominant three-pion mode. With the mass limits, $760 \leq M(3\pi) \leq 810$ MeV, 600 ω^0 events are seen above background in the three-pion effective-mass spectrum. From these it can be estimated that the natural width of the ω^0 is 6^{+3}_-6 MeV; this constitutes an appreciable lowering of the upper limit on the ω^0 width given by previous analysis.

On the basis of 40 events seen above background in the neutral-mass spectrum of Reaction (A), the neutral-to-charged ratio $(\omega^0 \rightarrow \text{neut})/(\omega^0 \rightarrow \pi^+ + \pi^- + \pi^0)$ has been determined to be $10 \pm 3\%$.

The reaction



which has been useful for analysis of the 1385-MeV Y_1^* , has yielded a narrow peak at 780 MeV in the pion-pion mass spectrum for a specially selected sample in which Y_1^* 's have been partially eliminated. Although complicated by the presence of the broader ρ^0 resonance, the fifteen events in the peak may possibly be examples of the predicted two-pion decay of the ω^0 .

Since the last report, the data on the η^0 meson from the reaction $K^- + p \rightarrow \Lambda^0 + \eta^0$ at 1.22 BeV/c have been increased by only 15%. The sample of 40 η^0 events represents the entire data available; approximately five events of the type $\eta^0 \rightarrow \pi^+ + \pi^- + \gamma$ were observed; these indicate a branching ratio of $\frac{\eta^0 \rightarrow \pi^+ + \pi^- + \gamma}{\eta^0 \rightarrow \pi^+ + \pi^- + \pi^0} \approx 10\%$.

A preliminary report of this analysis may be found in the Proceedings of the 1962 International Conference on High-Energy Physics at CERN (to be published).

(MF-L, DOH, JJM, JBS, FTS, and MLS)

Study of $K^- + p \rightarrow Y^{*\pm} + \pi^+$ at 1.22 and 1.51 BeV/c

At 1.22 BeV/c, about 525 positive Y_1^* 's and 650 negative Y_1^* 's have been fitted with mass limits $1340 \leq M(Y^*) \leq 1430$ MeV. These represent the total yield of the film taken at 1.22 BeV/c. The projection of Λ momentum on the normal to the Y^* production plane yields a distribution $1 + a(\hat{\Lambda} \cdot \hat{n})^2$, with $a = 0.69 \pm 0.22$ for the combination of Y_1^{*+} and Y_1^{*-} data (events with production-angle cosine, $Y^* \cdot K$, less than 0.5). This result agrees with that earlier obtained by Ely et al.¹ and tends to indicate a spin greater than 1/2 for the Y_1^* . Lambda polarization along the normal, $\hat{P}_\Lambda \cdot \hat{n}$, vs the quantity $\hat{\Lambda} \cdot \hat{n}$ shows a $(\hat{\Lambda} \cdot \hat{n})^2$ dependence; while Λ polarization along the "magic" direction, $\hat{P}_\Lambda \cdot \hat{m}$, vs the quantity $\hat{\Lambda} \cdot \hat{m}$ shows a $(\hat{\Lambda} \cdot \hat{m})^4$ dependence, where $m = -\hat{n} + 2(\hat{n} \cdot \hat{\Lambda})\hat{\Lambda}$. These observations constitute further evidence against spin of 1/2 and indicate the state of the Y_1^* to be $P_{3/2}$ rather than $D_{3/2}$ (spin 3/2, rather than higher spin, being assumed).

At 1.51 BeV/c, about 500 positive Y^* 's and 430 negative Y^* 's have been analyzed with mass limits $1340 \leq M(Y^*) \leq 1430$ MeV. There is evident nonuniform population of the Y^* mass bands of the Dalitz plot ($M_{Y^{*+}}^2$ vs $M_{Y^{*-}}^2$); this appears to be the result of ρ - Y^* interference. The pion-pion mass spectrum, with the events within the Y^* mass limits eliminated, shows the ρ meson clearly. The $\Delta^0 \pi^+$ mass spectrum shows an appreciable peak, suggesting a 1660-MeV $T = 1$ resonance. This is undergoing further study.

A preliminary report of this analysis may be found in the Proceedings of the 1962 International Conference on High-Energy Physics at CERN (to be published).

(DOH, JJM, and JBS)

K^- -Deuterium Interactions at 1.51 BeV/c

Approximately 22,000 pictures were taken of interactions in deuterium produced by an incident K^- of 1.51 BeV/c momentum. These have been partially scanned and analyzed for events yielding Λ 's or K^0 's, cascades, inelastically produced K^- 's, and Σ 's. Y_1^* production by K^-n interactions is being compared with Y_1^* production by K^-p interactions. Collaboration has been initiated through which members of the Powell Group can carry out a special study of the "internal conversion" of cascade hyperons to produce two hyperons of strangeness -1.

(MHA, AB-G, JBS, RDT, and SGW)

¹R. P. Ely, S. Y. Fung, G. Gidal, Y. L. Pan, W. M. Powell, and R. S. White, Phys. Rev. Letters 7, 461 (1961).

Study of $K^- + p \rightarrow \Xi^- + K^+$ and $\Xi^0 + K^0$

Approximately 800 Ξ^- and more than 100 Ξ^0 hyperons have been produced in the reaction $K^- + p \rightarrow \Xi + K$. Most of the data were obtained at 1.51 BeV/c.

A preliminary analysis of this work was made to determine the Ξ^- decay parameters, α_{Ξ^-} , β_{Ξ^-} , and γ_{Ξ^-} . The parameter α_{Ξ^-} , which measures the amount of parity nonconservation in the decay process, was found to be fairly large, namely, $\alpha_{\Xi^-} = 0.45 \pm 0.11$. The parameter β_{Ξ^-} , which in the absence of final-state interaction between the Λ^0 and π^- should be zero, was found to be equal to $\beta_{\Xi^-} = -0.63 \pm 0.31$, thereby suggesting that the $\Lambda^0 \pi^-$ final-state interaction plays a role. The parameter γ_{Ξ^-} , which measures the difference between the S-wave and P-wave decay intensities, was found to be $\gamma_{\Xi^-} = 0.63 \pm 0.31$, indicating that the S wave dominates the P wave.

An alternative set of parameters was also found that did not fit the data nearly as well as the above set. In fact, this latter set was only 1/40 as likely as the former set.

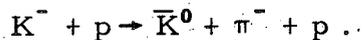
In the near future, information will be presented about masses, lifetimes, spins, decay modes, excited Ξ states, Ξ interactions with hydrogen, and the production mechanisms for both Ξ^- and Ξ^0 hyperons.

A preliminary report on this analysis may be found in the Proceedings of the 1962 International Conference on High-Energy Physics at CERN (to be published).

(LWA, JPB, GRK, JBS, FTS, MLS, and HKT)

Study of K^* Production and Decay

At the incident momentum of 1.22 BeV/c, approximately 3500 K^- interactions involving V^0 two-prong events have been analyzed, of which about 558 were examples of the reaction

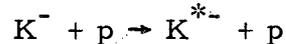


These were analyzed with the objective of obtaining the spin and parity of the $K-\pi(K^*)$ resonance as well as a better determination of its central value and width. The previous work of Alston et al.² has excluded the possibility of spin > 1 . The recent work of Chinowsky et al.³ has determined the spin of the K^* to be ≥ 1 . Putting these two experiments together, one concludes that the spin is 1.

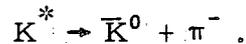
²M. Alston, L. W. Alvarez, P. Eberhard, M. L. Good, W. Graziano, H. K. Ticho, and S. G. Wojcicki, Phys. Rev. Letters 6, 300 (1961).

³W. Chinowsky, G. Goldhaber, S. Goldhaber, W. Lee, and T. O'Halloran, Phys. Rev. Letters 9, 330 (1962).

The analysis of the 1.22-BeV/c data is now complete. It has been found that the majority (about 3/4) of the $\bar{K}^0 p \pi^-$ events proceed via the two-body mode.



followed by the decay



The indications are that the width of the resonance is considerably larger than reported previously,² and that the central value lies at 890 MeV. The determination of these two parameters is hampered at this incident momentum because the resonance lies at a mass that is close to the maximum kinematically allowed value.

The decay distributions of the K^{*-} resonance have been analyzed to see if they exhibit any anisotropy. If the K^{*-} were produced in a peripheral collision of the incoming K^- with a virtual pion, then one would expect a distribution characterized by cosine-squared with respect to the incident K^- direction, assuming the K^{*-} spin to be 1. At 1.22 BeV/c, the distributions are not consistent with this expectation, and thus argue against the peripheral model.

The study of the same reaction at the K^- incident momentum of 1.51 BeV/c has so far produced approximately 900 K^{*-} events. Analysis of these data is currently in progress.

A preliminary report on this analysis may be found in the Proceedings of the 1962 International Conference on High-Energy Physics at CERN (to be published),

(MHA, GRK, HKT, and SGW)

Study of K^- -p Interactions in the 1.1-BeV/c Region

The 72-inch hydrogen bubble chamber was exposed to K^- at incident momenta of 1.03 and 1.09 BeV/c, which corresponds to about 350 MBE's. Because of the beam-momentum spread and ionization loss in the chamber, the momentum region covered extends from about 0.95 to 1.11 BeV/c. The purpose of the exposure is to study the behavior of various reactions in the region of the isotopic spin-zero resonance in K^-p total cross section.⁴ All the film has been scanned twice, and approximately 90% of the events have been measured. The analysis is too incomplete at this time to permit the drawing of any definite conclusions as to the spin and parity of the resonance.

(MHA, GRK, DHM, CGW, and SGW)

⁴L. T. Kerth, Rev. Mod. Phys. 33, 389 (1961).

Study of Resonances in the $\Sigma\pi$ System

In order to investigate the resonances in the $\Sigma\pi$ system we have analyzed the reactions

$$1.22\text{-BeV/c } K^- + p \rightarrow \Sigma^\pm \pi^\mp \pi^0 \text{ (c.m. energy 1895 MeV),} \quad (\text{A})$$

$$\rightarrow \Sigma^\pm \pi^\mp \pi^+ \pi^- \quad (\text{B})$$

$$\rightarrow \Sigma^0 \pi^0 \pi^+ \pi^-, \quad (\text{C})$$

and

$$1.51\text{-BeV/c } K^- + p \rightarrow \Sigma^\pm \pi^\mp \pi^+ \pi^- \text{ (c.m. energy 2025 MeV).} \quad (\text{D})$$

The reactions (A) show strong enhancements in the region of the neutral system corresponding to 1405 and 1520 MeV, in agreement with the $T = 0$ resonances previously discovered by Alston et al.⁵ and Bastien et al.⁶ at 1405 MeV, and by Ferro-Luzzi et al.⁷ at 1520 MeV. To a very good approximation all the reactions (B) and (C) at 1895 MeV can be described as proceeding via the production of a 1405-MeV resonance and two additional pions. At 2025 MeV almost all the examples of the reactions (D) are consistent with the assumption that the events produce either a 1405- or a 1520-MeV resonance in the ratio of about 3:1. All the reactions agree with a full width of 50 ± 10 MeV for the 1405-MeV resonance and 25 ± 5 MeV for the 1520-MeV resonance.

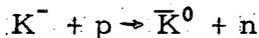
The $\Sigma 3\pi$ data at 2025 MeV are insufficient at present to decide whether there is any enhancement in the doubly charged $\Sigma\pi$ system that might be attributed to a predicted $T = 2$ global symmetry resonance in the 1560-MeV region. The total analysis is based on approximately 7500 events, all of which have been measured. Second measurements are currently being done to finish the analysis.

A preliminary report on this analysis may be found in the Proceedings of the 1962 International Conference on High-Energy Physics at CERN (to be published).

(MHA, LWA, MF-L, AHR, HKT, and SGW)

K^- -p Charge Exchange at 1.22 BeV/c

The reaction



⁵ M. Alston, L. W. Alvarez, P. Eberhard, M. L. Good, W. Graziano, H. K. Ticho, and S. G. Wojcicki, *Phys. Rev. Letters* **6**, 698 (1961).

⁶ P. Bastien, M. Ferro-Luzzi, and A. H. Rosenfeld, *Phys. Rev. Letters* **6**, 702 (1961).

⁷ M. Ferro-Luzzi, R. D. Tripp, and M. B. Watson, *Phys. Rev. Letters* **8**, 28 (1962).

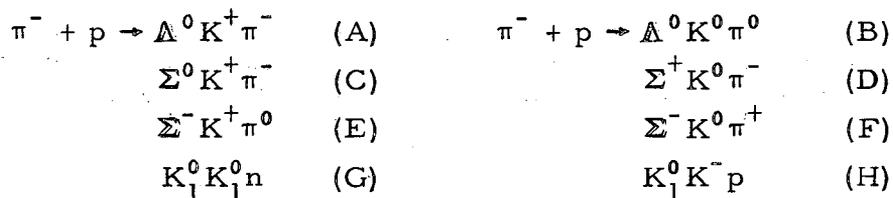
has been studied at an incident K^- momentum of 1.22 BeV/c (1895 MeV total c.m. energy). The angular distribution for this reaction in the center of mass shows a prominent backward peaking of the \bar{K}^0 . This behavior had been noticed in earlier experiments at lower K^- incident momenta, starting at about 760 MeV/c and increasing steadily up to 1.22 BeV/c. Preliminary results at 1.51 BeV/c incident momentum (2025 MeV total c.m. energy) indicate the effect to have disappeared or--at any rate--to have lost its spectacular character.

A preliminary report on this analysis may be found in the Proceedings of the 1962 International Conference on High-Energy Physics at CERN(to be published).

(MF-L, FTS, and MLS)

Study of Strange-Particle Resonant States Produced in $\pi^- + p$ Interactions

We have analyzed the three-body final states



at incident momenta of 1.51 to 2.25 BeV/c. Based on a first-scan sample of approximately 13,000 events, 2500 of the above reactions have been identified. The remainder of the sample consists mainly of two- and four- or five-body final states under present consideration. A study of the effective-mass distributions in reactions (A) through (F) indicates that the three resonances, Y_1^* (1385 MeV),⁸ Y_0^* (1405 MeV),^{5,6} and Y_0^* (1520 MeV)⁷ are strongly produced. In addition, the data for the $Y\pi$ systems at momenta greater than 2.05 BeV/c show an enhancement in the region of 1660 MeV. Since there are Λ^0 events in this peak, the enhancement is attributed to the $I = 1$ system. The K^* (885-MeV) resonance is produced in all final states except (D), where the $K\pi$ system is in an $I = 3/2$ state. There is some evidence for an enhancement in the $K-\pi$ system at approximately 730 MeV, although at this time the statistical significance of the peak is such that the effect cannot be judged a definite resonance.⁹

⁸M. Alston, L. Alvarez, P. Eberhard, M. Good, W. Graziano, H. Ticho, and S. Wojcicki, Phys. Rev. Letters 5, 520 (1960).

⁹G. Alexander, G. R. Kalbfleisch, D. H. Miller, and G. A. Smith, Phys. Rev. Letters 8, 447 (1962); also $K-\pi$ Mass Distributions for $\pi^- + p \rightarrow \gamma + K + \pi$ at Incident Momenta of 1.89 through 2.24 GeV/c, UCRL-10291, June 1962.

An analysis of 158 events of the type (G) and (H) has recently been completed. The $\bar{K}^0 K^0$ effective-mass distribution shows a marked enhancement in the region of 1 BeV (Q-value of the system is about 25 MeV), whereas the $K^- K^0$ distribution is consistent with phase-space predictions. Since the latter state is pure $I = 1$, we attribute the effect to the $I = 0$ $\bar{K}K$ system. That we detect only $K_1^0 K_1^0$ pairs leads to the conclusion that the system must have quantum numbers: even angular momentum, even spatial parity, and even G parity.¹⁰

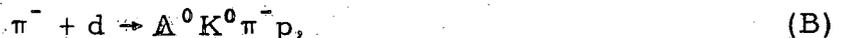
(GA, OID, LDJ, GRK, DHM, AR, JAS, and GAS)

Study of Strange-Particle Resonant States Produced in $\pi^- + d$ Interactions at 2.28 BeV/c

In order to search for the proposed $T = 2$ $\Sigma\pi$ global symmetry resonance we are in the process of studying the reaction



the doubly charged $\Sigma\pi$ system cannot be produced in three-body final states in the interactions on hydrogen. Preliminary data are too few to permit one to draw any conclusions. In addition to reaction (A) we have been studying the reaction



which, owing to the absence of the K^* resonance, has been selected to look for the 1660-MeV $Y\pi$ $I = 1$ resonance suggested in the $\pi^- p$ data. The results of this analysis should be forthcoming soon.

(GA, OID, LDJ, GRK, DHM, AR, JAS, and GAS)

The Reaction $\pi^- + p \rightarrow \pi^+ + \pi^- + n$ Below 800 MeV

The Lawrence Radiation Laboratory 72-inch liquid hydrogen bubble chamber has been exposed to beams of eight different energies from 360 to 770 MeV kinetic energy (the settings at 360 and 770 MeV are from an earlier run as part of the Associated-Production Experiment). More than 3000 π^+ -production events have been analyzed. For beam energies in excess of $N_{3/2}^* + \pi$ threshold there is clear evidence for $N_{3/2}^*$ isobar production. The π^+ angular distribution indicates that these isobars prefer the backward hemisphere below 500 MeV, while above 600 MeV the opposite is observed. For the lowest incoming beam energies the neutron kinetic-energy distribution in the reaction c. m. system strongly favors low neutron energies,¹¹ but shows no other striking effects.

(JK, JAS, and RDT)

¹⁰Gideon Alexander, Orin I. Dahl, Laurance Jacobs, George R. Kalbfleisch, Donald H. Miller, Alan Rittenberg, Joseph Schwartz, and Gerald A. Smith, Final-State Interactions in the $\pi^- + p \rightarrow K\bar{K}N$ Reactions (UCRL-10524, Oct. 1962), Phys. Rev. Letters (to be published).

¹¹J. Schwartz, J. Kirz, and R. D. Tripp, Bull. Am. Phys. Soc. 4, 282 (1962).

Associated-Production Experiment (72-Inch Chamber) Parity Conservation
in $\pi^- + p \rightarrow \Lambda^0 + K^0$

In a complete sample of 2700 Λ^0 decays produced in the reaction $\pi^- + p \rightarrow \Lambda^0 + K^0$ at 1035 MeV/c, no evidence was found for parity nonconservation in the production process. The decay asymmetry components in the production plane were zero, with errors ± 0.03 . The results of this analysis were reported at the 1962 International Conference on High-Energy Physics at CERN.

(JAA, BBC, FSC, RLG, RAG, LJJ, GM, LRP, and DY)

High-Angular-Momentum States in $\pi^- + p \rightarrow \Lambda^0 + K^0$

On the basis of about 6000 events at pion momentum 1035 MeV/c, there seem to be states up to at least $F_{5/2}$. The results of this analysis were reported at the 1962 International Conference on High-Energy Physics at CERN.

(JAA, BBC, FSC, RLG, RAG, LJJ, GM, LRP, and DY)

$\pi^- + p \rightarrow \Lambda^0 + K^0$ at Its Threshold

Both S and P waves seem to be present close to threshold. An attempt is being made to extrapolate between this threshold (about 903 MeV/c) and 1035-MeV/c data. The results of this analysis were reported at the 1962 International Conference on High-Energy Physics at CERN.

(JAA, BBC, FSC, RLG, RAG, LJJ, GM, LRP, and DY)

Charge Symmetry in the Associated-Production Process

By comparing absolute cross section, angular distribution, and polarization of the Λ^0 in

$$\pi^- + d \rightarrow K^0 + \Lambda^0 + n \quad (A)$$

and

$$\pi^+ + d \rightarrow K^+ + \Lambda^0 + p \quad (B)$$

and in several other closely related processes, one can test the reactions for charge symmetry. No detectable differences were found between these reactions (except for the differences in charge that distinguish them.) Thus the reactions exhibit charge symmetry. The statistical errors are about 10% on all the quantities tested. The results of this analysis were reported at the 1962 International Conference on High-Energy Physics at CERN.

(FSC, JRH, JBS, and MLS, in collaboration with Duke University and Johns Hopkins University)

Neutral Branching Ratios of η 's Produced in $\pi^+ p$ Interactions at 1170 MeV/c

Four-prong events and two prongs with an associated γ -ray conversion are being examined in an attempt to obtain the branching ratios for

$$\eta \rightarrow \pi^+ + \pi^- + \gamma,$$

$$\pi^+ + \pi^- + \pi^0,$$

$$\gamma + \gamma,$$

and

$$\pi^0 + \pi^0 + \pi^0.$$

(JAA, BBC, FSC, RLG, RAG, LJL, GM, LRP, and DY, in collaboration with E. C. Fowler, Yale)

Low-Energy $K^- + p$ Experiments (15-Inch Chamber)

Y_1^* -Spin Analysis

Approximately 1000 events of the reaction $K^- + p \rightarrow Y_1^* + \pi$; $Y_1^* \rightarrow \Lambda^0 + \pi$ from the 760-MeV/c K^- run of 1960 have been studied in some detail in an attempt to decide the spin of the Y_1^* . Using the model proposed by Dalitz and Miller,¹² we have attempted to fit the data to the S- and P-wave production of a Y_1^* of spin either 1/2 or 3/2. From a comparison of the goodness of fit of the data to the several hypotheses, we have attempted to determine the Y_1^* spin. So far the results are rather difficult to interpret, and work is still in progress.

(JPB)

$K^- - p$ Interactions Near 760 MeV/c

The Lawrence Radiation Laboratory 15-inch hydrogen bubble chamber has been used to study $K^- - p$ interactions at 620, 760, and 850 MeV/c. A study of the two-body final states shows significant enhancements in the pure $I=1$ $Y\pi$ and $Y\pi\pi$ total cross sections at 760 MeV/c. These are interpreted as manifestations of a Y_1^* (1660 MeV) excited hyperon. Furthermore, a study of the angular distributions for these final states clearly indicates that the spin of the resonance would be 3/2.

(PB and JPB)

Elastic Scattering and Charged-Hyperon Production at 75 to 300 MeV/c

Elastic scattering and charged-hyperon production for the low-energy $K^- - p$ interaction (75 to 300 MeV/c) of the 1960 exposure of the 15-inch hydrogen chamber are being completed. New programs are being written to expand the analysis of the low-energy $K^- - p$ system beyond the zero-effective-range analysis carried out for the data of the 1958 exposure.

(WEH and RRR)

¹²R. H. Dalitz and D. H. Miller, Phys. Rev. Letters 6, 562 (1961).

Determination of the Σ - Λ Parity

In a previous publication⁷ the existence of an excited hyperon of mass 1520 MeV and full width 16 MeV was established; the state was found to have isotopic spin 0, spin 3/2, even parity with respect to K^-p , and a $\bar{K}N: \Sigma\pi: \Lambda\pi\pi$ branching ratio of 3:5:1. From a further study of the angular distributions and polarizations of the different $\Sigma\pi$ charge states the $Kp\Sigma$ parity was concluded to be odd.¹³ Combining this with another result on odd $Kp\Lambda$ parity,¹⁴ one may conclude that the Σ - Λ parity is even.

The $Kp\Sigma$ parity result was based on data analyzed in the vicinity of 400-MeV/c K^- on hydrogen. Subsequently all the K^-p data between 250 and 513 MeV/c have been subjected to a least-squares fit by using zero-effective-range amplitudes for the nonresonant S, P, and D waves and a resonant $D_{3/2}$ amplitude. Only odd $Kp\Sigma$ parity is found to fit the data satisfactorily.

(MF-L, RDT, and MBW)

Hyperon Production by K^- Interactions in Deuterium

Hyperon production by K^- interactions in deuterium at a laboratory-system momentum of 200 MeV/c has been analyzed. The experiment was performed at the Bevatron in the Lawrence Radiation Laboratory 15-inch deuterium bubble chamber. The reactions are dominated by three-body final states. Branching ratios between the several final states provide two independent verifications of the charge-independence hypothesis. The ratios are in reasonable agreement with those predicted from the K^-p interaction. Analysis of the energy distributions in the final state indicates the presence of final-state scattering as well as a dominating impulse type of the K^- -nucleon interaction.

(OID)

Antiproton Experiment (72-inch Chamber)

An analysis of two-prong interactions of the 1.65-BeV/c antiprotons in the 72-inch hydrogen bubble chamber is nearly complete. The inelastic two-prong interactions have been studied. The results of this analysis will soon be published.

(GAL)

¹³R. D. Tripp, M. B. Watson, and M. Ferro-Luzzi, Phys. Rev. Letters 8, 175 (1962).

¹⁴M. M. Block, F. Anderson, A. Pevsner, E. Harth, J. Leitner, and H. Cohn, Phys. Rev. Letters 3, 291 (1959).

DATA REDUCTION

Programming and Computer Efforts

A number of programs that are essential to the data-reduction process were discussed in the preceding semiannual report. For purposes of review, these systems do the following jobs:

PANAL takes the output from the measuring projectors and performs checks on the format of the measurements as well as on the measurements themselves.

PACKAGE performs the geometrical reconstruction of the event in the chamber and then subjects it to a kinematical constraint subroutine that searches for the best fit to the input data on the assumption of an event hypothesis.

EXAMIN AND SUMMEX perform detailed calculations on the raw output from PACKAGE and plot the data in histograms, scatter diagrams, etc.

A new program, LINGO, has been added to the system. This program maintains and performs library operations on an event catalog on magnetic tape. Serving as a control index in parallel with the physics analysis routines, it connects to the analysis flow only when controlling what events are to be measured and when receiving the final results of those measurements. Such a system is fundamental in large experiments (thousands of events).

The QUEST program, discussed in a preliminary sense in the preceding semiannual report, has been essentially completed. It is an on-line computing system that can be used by a physicist to analyze unusual bubble-chamber events. The production version of PACKAGE has been modified so that the physicist can control the progress of a specific event through the subroutines of PACKAGE. Feedback from the computer to the operator permits him to decide what hypothesis he should try next, depending upon the results already obtained. Because the physicist requires time to think what to do next, the QUEST system has been designed so that it can interrupt and then restore other programs.

Franckenstein System

The scanning and measuring system for the 72-inch hydrogen bubble chamber is in continual operation, with four measuring projectors and ten scanning projectors. One of the measuring projectors previously used to measure film from the 15-inch bubble chamber has been converted to handle film from the 72-inch chamber. This machine is now beginning production work, and operators are being trained in its use. This will increase the measuring capability of the data-analysis system for the 72-inch bubble-chamber.

The 15-inch bubble-chamber system has been decreasing because there have been no new exposures with this chamber. The system now consists of one measuring projector and one scanning projector. One measuring projector and eight scanning projectors are on loan to other groups in the Laboratory.

Data-Reduction OperationsPersonnel (Alvarez Scanning and Measuring Group)

The total effort in full-time equivalents was 63 for May 1962 and rose to 80 for June 1962, when many part-time employees went to full time for the summer. In October the group strength returned to 63 full-time equivalents.

Scanning

During this 6-month period (May through October 1962) the bubble-chamber film was scanned as follows.

<u>Experiment</u>	<u>Scanning</u>	<u>Number of rolls</u>
4	1(π^- in H_2)	159
4	2(π^- in H_2)	30
4	1(π^+ in H_2)	66
4	2(π^+ in H_2)	57
4	Special	111
6	1(π^- in H_2)	25
6	2(π^- in H_2)	25
6	Special 1	17
6	Special 2	17
7	1(K^- in H_2)	457
7	2(K^- in H_2)	357
7	1(K^- in D_2)	25
8	1(π^- in H_2)	268
8	2(π^- in H_2)	131
8	1(π^- in D_2)	51
Total 72-inch bubble-chamber rolls scanned		1,796

Measuring

The measuring activity during this half year was as follows.

<u>Measuring projector</u>	<u>Bubble chamber</u>	<u>Measuring hours</u>	<u>Instrument hours</u>	<u>Number of events</u>
IA	15 inch	353	0	1,635
ID	15 inch	454	16	2,270
Total		807	16	3,905
IIA	72 inch	2,999	243	17,744
IIB	72 inch	3,112	110	16,609
IIC	72 inch	2,577	186	14,271
IID	72 inch	2,396	195	12,720
Total		11,084	734	61,344

The Spiral Reader

The spiral reader is now operational though not yet working on a production basis. Improvements are continually being made in the filter program and other parts of the system. At present about 70% of the two-prong events measured can be processed completely, and the results compare favorably with Franckenstein measurements of the same events. Of the 30% that fail, it seems likely that improvements can soon correct one-half to two-thirds of these. The remaining 10 to 15% failures will probably be difficult to eliminate. Single-vertex events are measured in about 6 minutes. Improvements being worked on in the control logic of the machine will speed up the measurements. The ultimate speed is expected to be 3 or 4 minutes per event.

The SMP System

A prototype version of an instrument for scanning and measuring bubble-chamber film, the SMP (described in UCRL-10109) has been built and tested. Tests of the prototype connected to an IBM 709 computer have demonstrated the feasibility of this mode of operation, and have shown that the instrument is capable of detecting bubbles even on low-quality film. The measurement accuracy (for a 0.6-cm track segment made up of bubbles 30 μ in diameter) was 6 μ .

Three improved versions of the prototype SMP are presently nearing completion. A computer program has been coded that is capable of ingesting, checking, and analyzing the data from at least three SMP's simultaneously operating on-line to an IBM 709 computer. Debugging of the complete operational system is just getting under way.

PEBL

The electronic analog of the KICK-GUTS system, PEBL, described in the preceding report, has been completed to the extent of having the capability for analysis of one-vertex events involving five or fewer particles. Greater capability is being added on a noninterfering basis. The analog is being used currently in a systematic study of the KICK failures that occurred among events of the two-prong vee topology in the 1.22-BeV/c K72 run. The average time spent determining the cause of a failure, including usually a re-examination on the scanning table (but no remeasurement), is about 1/2 hour. This process reveals that almost all the KICK failures are the result not of faulty measurement but rather of incorrect interpretation. The goal, not yet reached, is to determine the distribution of the various causes and final disposition of the failures well enough to estimate possible effects on other results. This undertaking should end in a few months.

BUBBLE CHAMBER OPERATION AND DEVELOPMENT

72-Inch Chamber Operations

The 72-inch chamber continued operating on the K72 experiment until a broken refrigerator line necessitated termination of the run a few days before the shutdown of the Bevatron. Approximately 220,000 photographs (367 rolls) of K^- and π^- in hydrogen and 67,000 photographs (112 rolls) of K^- and π^- in deuterium were taken during this report period. Since the shutdown of the Bevatron, the operating crews have been utilized in repair and maintenance of the 72-inch chamber, development of better and more reliable spectrometers and construction, and component testing of the 25-inch bubble chamber.

25-Inch Chamber Development

The 25-inch chamber, being constructed as a general laboratory facility, has proceeded well into the "hardware" stage. The magnet iron and support stand have been received and assembled. The first six coils for the magnet are due from the supplier by the end of November and the remaining six coils by the first of the year. The vacuum-system components are being assembled and fitted to the vacuum tank. The control-panel assembly is nearing completion. The stainless steel castings for the chamber and window flanges have been received and are being machined. Construction of the inflatable gaskets for sealing the windows is under way.

Some difficulty has been encountered in fabrication of the expansion bellows. When the two bellows halves were welded together, radial cracks appeared. These were patched by hand welding. The bellows were pulsed at double the normal stroke in the rapid-cycle test device at liquid nitrogen temperature for two million pulses. The bellows were then leak-checked and found to be tight. A room-temperature cycling test was performed, and the repaired cracks failed after 1/2 million pulses. Metallurgical investigation suggested a change in the type of stainless steel. A test set of bellows is being fabricated and will be tested in the near future.

During this period, effort has been directed toward development of a fast cycling system to permit more economical procurement of track photographs. We are designing a photographic system that should be capable of obtaining up to five stereo triplets per Bevatron beam burst.

Primary elements of the chamber light-source system have been tested and have demonstrated the necessary capability. An Edgerton FX-26 lamp was pulsed approximately four flashes in 350 msec with a 5-sec cool-down period.

Quartz camera ports and the large optical blanks have been received. Processing of the lens elements has been started. One of the blanks for the chamber precision window was cracked at Tinsley Laboratories (Berkeley). Although we have a spare blank, this has caused delay and may significantly extend the delivery date of the optics.

Matched lenses for the stereo camera have been received and are being tested by Lawrence Radiation Laboratory Technical-Photo group for distortion characteristics. A new film-drive system capable of handling the prodigious quantities of film required by fast cycling has been evolved and is in the detail-design stage.

Data acquisition has become relatively difficult owing to the low intrinsic brightness of commercially available digital displays. Work is progressing on conversion of the Industrial Electronic Digital Display Unit to flash operation. No test information is presently available.

The 25-inch chamber should be ready for an engineering test run with liquid hydrogen by the first part of May 1963.

PHYSICS RESEARCH

Walter H. Barkas in charge

STRANGE-PARTICLE RESEARCH

K⁻-Meson Reactions in Complex Nuclei

Angela Barbaro-Galtieri, Walter H. Barkas, Harry H. Heckman,
W. Zack Osborne, Jack W. Patrick, and Frances M. Smith

A program to study the role played by hyperon-pion and other resonances in the capture of K⁻ mesons in complex nuclei has been in progress for about two years.

The investigation of events in which the K⁻ meson interacts at rest, producing $\Sigma^{\pm} + \pi^{\mp}$, is nearing completion. A sample of some 250 such stars was chosen with the requirement that (a) if the Σ decayed in flight, its secondary came to rest in the stack; (b) the associated π came to rest in the emulsion with no inelastic scatterings along its path.

We have further separated the events showing only the $\Sigma^{\pm} \pi^{\mp}$ and those with $\Sigma^{\pm} \pi^{\mp}$ plus a recoil, blob, or electron from those showing additional prongs.

We are now gathering data on events that indicate multinucleon capture of the K⁻ meson. The purpose of this experiment is to find whether or not resonant states are involved in the multinucleon capture process. To date, we have located 54 events of the type $K^{-} + \begin{pmatrix} pp \\ np \end{pmatrix} \rightarrow \Sigma^{\pm} + p$, where the kinetic energies of the Σ and p are greater than 60 and 30 MeV, respectively. About one-half our scanning effort to locate these events is finished.

To complete the analysis of an unbiased sample of K⁻-meson interactions at rest, it was necessary to determine the momenta of a group of high-energy particles that left the emulsion stack or otherwise failed to come to rest in it. Some 97 momentum determinations have now been made by means of multiple-scattering measurements with the Koristka MS-2 digitized microscope and the Cooke scattering microscope. In order to have an additional check on these data, however, the entire group of events was also subjected to ionization measurements both at the track beginning and at the track terminus where feasible. Ideally 1000 blobs were counted in a single plate, and calibration was made on a similar high-momentum track of known velocity in that same plate. The emulsion stack "A" employed was the subject of extensive ionization measurements in a previous work.¹ This combined analysis is expected to yield a more accurate high-energy pion spectrum than either method used alone.

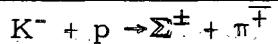
¹J. W. Patrick and W. H. Barkas, Nuovo Cimento, Suppl. 23, 1 (1962).

Hyperfragment Production Process

Jack W. Patrick and Piyare L. Jain

Analysis of K^- stars in which a hyperfragment and a pion were associated--referred to in the previous Semiannual Report--has not yet been completed. A preliminary check, begun on the charges or ranges (or both) of the particles involved, failed to agree with the previous measurements. A reanalysis is now in progress.

Energy-Momentum Balance in the Reactions



John N. Dyer, Walter H. Barkas, and Harry H. Heckman

The apparent anomaly in the energy and momentum balance in the reaction $K^- + p \rightarrow \Sigma^- + \pi^+$, previously reported,² has been the subject of further study. The measurements described in the preceding Semiannual Report have been completed, and our first results have been reported.³

An adjustment of the range-energy relation (mostly for pions in the neighborhood of 70 to 90 MeV) is indicated by our data and is at present being calculated. This and possibly other adjustments will reduce the anomaly but probably will not completely remove it. This work will be completed during the present report period.

PION RESEARCH

Mean Life of the π^0 Meson

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

Evaluation of the errors in the π^0 lifetime measurement, which was thought to have been completed in the last report period, is not yet finished, and a final mean-life estimate cannot be made.

Interactions of 16-BeV π^- Mesons with Protons

J. R. Burwell, Walter H. Barkas, A. G. Barkow,
Piyare L. Jain, G. Kane, Z. O'Friel, and Hla Shwe

Interactions in emulsion of 16-BeV π^- mesons, found in extensive along-the-track scanning, were analyzed to select from among them the ones that correspond to collisions with free protons. The number, angular distribution, and energy distribution of the secondary particles produced in these collisions have been measured, and analysis of the data is now in progress.

² John N. Dyer, Charged Σ -Hyperon Production and Decay: Energetics, Lifetimes, and Branching Ratios (Thesis), UCRL-9450, Nov. 1960.

³ Walter H. Barkas, John N. Dyer, and Harry H. Heckman, Energy Balance in $K^- + p \rightarrow \Sigma^\pm + \pi^\mp$, Bull. Am. Phys. Soc. 7, 469(1962).

HEAVY-ION RESEARCH

Neutrons Produced in Heavy-Ion Reactions

William G. Simon

Measurements of the neutron yield from bombardment of Au by O^{16} ions have been extended to a neutron energy of 25 MeV in the forward direction. These new measurements were made by using an external polyethylene radiator together with nuclear emulsions to detect the recoil protons. An abstract has been submitted for the APS winter meeting in the west: William G. Simon, Neutron Spectra from Heavy-Ion Bombardment, UCRL-10507 Abs., Oct. 1962.

Multiple Scattering of Heavy Ions

William G. Simon

Measurements were made of the multiple scattering of O^{16} ions in Au and zapon foils and of A^{40} ions in Al, Au, and zapon foils. No other such experiment is known to us. In those cases in which the Molière theory is applicable, the results agree well with the theory. (The Au foil was thinner than the minimum thickness for which Molière's theory applies, so that no comparison was made for gold.)

Charged Particles from O^{16} Interactions

Donald V. Reames

Analysis of the angular distribution of protons and alphas from 0° to 15° for O^{16} interactions in Al is continuing. Further scanning has also been done on the 0° magnetic analysis of particles from O^{16} interactions in Al, Ni, Ag, and Au. The spectra produced in the interactions of O^{16} on Ag have been included to see if there is a general decrease in the yields with increasing A of the target or if the decrease seen for Au is primarily due to competition with fission. Such information may make it possible to say on the average how early fission occurs in the de-excitation process.

An Automatic Counting Device for Heavily Ionized Tracks

Donald V. Reames

An attempt is being made to use the electrical conductivity of the solid shaft of silver left by heavy ions to count these ions. Thin layers (5 to 20μ) of K.5 emulsion were poured on electrically conducting Nesa glass and exposed to the 167-MeV O^{16} beam at normal incidence. The processed plates were then placed on a standard microscope stage, and the objective lens of the microscope was replaced by the tip of a fine ball-point pen. As the stage is driven under the pen, electrical contact is made between the pen and the glass surface when a track passes under the pen. A simple circuit has been made to count the resulting pulses.

Preliminary results indicate that the technique is quite feasible, although further development is necessary to improve its reliability. It is expected that a wide range of particles can be counted by this method, possibly including stopping alphas. The technique is currently being applied to the angular distribution of O^{16} ions scattered by thin Al, Ni, and Au foils.

DIRECT OBSERVATION OF THE MIRRORING OF GEOMAGNETICALLY TRAPPED PROTONS ON A DISCOVERER SATELLITE

Harry H. Heckman

(In cooperation with Dr. George Nakano, Lockheed Missiles and
Space Division, Palo Alto, California)

We are now analyzing a group of four small emulsion stacks (each 4 cm diam \times 0.5 cm) that were recovered on Sept. 1, 1962 from a space-oriented Discoverer satellite. The orbit was inclined 65.2° to the equator; apogee and perigee were 407 km and 178 km, respectively. The number of orbits was 65. Because of the low altitude of the satellite, only those geomagnetically trapped protons that mirrored over the South Atlantic (where the geomagnetic field has its lowest value) were detected. Limits can be set on the area over which the mirroring protons were detected. Moreover, the distribution of pitch angles we observe, a Gaussian with $\sigma = 7.8^\circ$, suggests that the region may be very small, and that pitch-angle distribution is close to the actual one. Preliminary results on the orientation of the mirror planes in the emulsions show that the inclination I of the magnetic field was about 40° , corresponding to a geomagnetic latitude $\lambda_m = 22.8^\circ$ at the point of maximum intensity. We also have observed an asymmetry in the flux of protons arriving at our detectors from the west relative to the flux arriving from the east. The asymmetry, an effect attributable to the residual atmosphere at this altitude, is consistent with the calculations by Lenchek and Singer, who first suggested that the asymmetry would exist.⁴ Energy and flux measurements are now being taken.

UNIVERSAL RANGE TABLE

Walter H. Barkas

As a contribution to the work of the Subcommittee on Penetration of Charged Particles in Matter of the National Research Council, a universal range-energy table has been prepared. It has been issued as a report.⁵ This table is consistent with the most accurate data available for all stopping materials. With only a few restrictions it permits interpolation to obtain the range of any particle at any energy in any material.

VIDEO TRACK ANALYZER

Harry H. Heckman and Walter H. Barkas

The construction of the television microscope described in the preceding report has been completed. The initial test operation of the instrument was to measure the mean track width of stopping heavy ions. Ions of carbon, neon, and argon, accelerated by the Hilac, were used. The measurement of mean track width over a range of 100 to 200 μ was found to be reproducible to about $\pm 1.7\%$ for a given track. A sample of five tracks of

⁴A. M. Lenchek and S. F. Singer, J. Geophys. Res. 67, 4073 (1962).

⁵Walter H. Barkas, The Range-Energy Function, UCRL-10292, Aug. 1962.

each of the ions listed above was measured. The σ of the distribution of the mean track width for all ions was about 2%. The ions were completely resolved with respect to charge for ranges greater than 60 μ .

Several functional improvements have been made on the microscope. The operational tests showed that the track signal varies with the position of the track in the electronic gate. It is upon this problem that we are now concentrating.

PHYSICS RESEARCH

Kenneth M. Crowe in charge

MESIC x-RAY STUDIES

Alan Astbury and Robert Shafter

A program of measurements of π and μ mesic x rays produced in transitions of mesons between Bohr orbits of various elements is in progress. A bent-crystal x-ray spectrometer is being used for precision energy measurements of the x rays in the range 20 keV to 1 MeV. The experiments are being performed in the meson cave of the 184-inch cyclotron.

The spectrometer utilizes an 8x8-in. quartz crystal with a 6.5x6.5-in. usable aperture. A run has been made using the 411-keV x rays from a Au^{198} source, and the resolution was found to be 0.3%.

Precise measurements of mesic x rays would be useful for a variety of reasons, such as determination of the pion and muon masses and more precise knowledge of nuclear charge distributions. Measurements of energy-level splittings due to the spin of the mesons can be used to study magnetic-moment effects, radiative effects, and nuclear quadrupole moments.

THE K^+ DECAY

Robert Beck and Roy P. Haddock*

This experiment, the first phase of which was performed at the Bevatron in the summer of 1961, seeks to determine the branching ratios for the different K^+ decay modes and to study the momentum spectra of the charged decay products, using a magnetic spectrometer in coincidence with a counter hodoscope. Data were taken in the form of four trace oscilloscope photographs recording the counter pulses, and a time-of-flight record of the event was photographed to assist in particle identification.

Four computer programs have been instituted to aid the analysis: IDEAL, EXACT, SELECT, and SHOWER. The first two study the focusing properties of the spectrometer magnet and determine the momentum ranges of acceptance into the various "bins" of the counter hodoscope. The SELECT program can then identify the various decay modes. The SHOWER program, based on Monte Carlo calculations, will be used to estimate the electron-detection efficiency for the K_{e3} mode.

The analysis is presently in progress. Ten thousand useful events have been examined, and tentative results on the $\text{K}_{\mu 2}/\text{K}_{\pi 2}$ relative branching ratios will soon be obtained. A second run is being considered, to measure the branching ratios of the rarer modes and the momentum spectra of the charged secondaries more closely. We also wish to investigate the angular correlation in the $\text{K}_{\mu 3}$ and K_{e3} decays from K^+ at rest. Such a study would yield information as to the nature of the interaction leading to these decays.

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BOUND-MUON DECAY

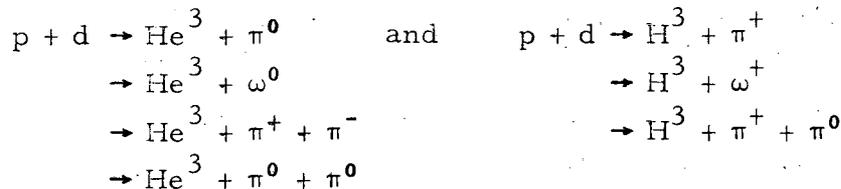
Philip Beilin and Alan Astbury

An experiment of the muon decay, $\mu \rightarrow e + \bar{\nu} + \nu$, from bound atomic states has been performed to study the distortion of the electron spectrum. The run was recently concluded at the 184-inch cyclotron with a 180° magnetic spectrometer in conjunction with counter telescope arrangements to detect and measure the momentum spectrum of the decay electrons for μ^- stopped in copper.

Interest in this problem stems from two considerations: The experiment has been performed once to date;¹ furthermore, experiments by several groups indicate an anomalously high decay rate--when taken as a function of the atomic number of the binding nucleus Z --in the neighborhood of iron.² Theory predicts no such behaviour. However, the electron spectra for bound muon decay has been calculated theoretically.³ Thus, an experiment examining the electron spectrum would represent a definitive check on theoretical predictions.

MESON PRODUCTION IN $p + d$ COLLISIONS AND
THE $I = 0$ π - π INTERACTIONAlexander Abashian,[†] Norman E. Booth,[‡] Kenneth M. Crowe,
Roger E. Hill, and Ernest H. Rogers*

High-resolution momentum spectra of He^3 and H^3 nuclei produced in the reactions



were studied in a series of three experiments performed at the 184-inch cyclotron. Each spectrum exhibits a peak due to single pion production and a continuum due to the double pion production. Moreover, an anomalous bump has been observed in the He^3 spectra which has been interpreted as an $I = 0$ virtual dipion with a scattering length of $2 \hbar/\mu c$. The preliminary re-

¹G. Culligan et al., in Proceedings of the 1961 Conference on Elementary Particles, Aix-en-Provence, p. 143.

²cf. R. W. Huff, Ann. Phys. **16**, 288 (1961), p. 292. However, the results of an experiment only recently published reports seeing no anomaly in the decay rate: I. M. Blair et al., Proc. Phys. Soc. (London) **86**, 938 (1962).

³H. Überall, Phys. Rev. **119**, 365 (1960); V. Gilinsky and J. Mathews, Phys. Rev. **120**, 1450 (1960); R. W. Huff, *op. cit.*

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†Present address: Enrico Fermi Institute, Univ. Chicago, Chicago, Ill.

‡Present address: Aerospace Corporation, El Segundo, California.

sults have been reported,⁴ and the final results and interpretation are to be presented in a series of four papers.⁵

The main problems of interest are the results of the measurements on single pion production and the determination of the spin and parity of the anomalous bump as well as its interpretation. Absolute cross sections for the reactions $p + d \rightarrow \text{He}^3 + \pi^0$ and $p + d \rightarrow \text{H}^3 + \pi^+$ have been measured at several angles and energies, and results are in good agreement with other experiments. Comparison of the widths and shape of the single pion peaks with our resolution calculations enabled us to check the experimental resolutions at He^3 momenta corresponding to 2π production. Moreover, combining our measured cross sections with the cross sections for the process $p + p \rightarrow d + \pi^+$, we calculated the He^3 form factor through the use of the impulse-approximation integral relating the two processes

$$\text{and } \begin{aligned} p + d &\rightarrow \text{H}^3 + \pi^+ \\ p + p &\rightarrow d + \pi^+ \end{aligned}$$

In the last of the three experiments the spin and parity of the anomaly was determined; the $I = 0$ isotopic spin state was inferred from a comparison of the He^3 and H^3 momentum spectra. The experiment consisted in measuring the relative numbers of x rays and charged pions in coincidence with the He^3 of several different momenta. Since the anomaly has an extremely short lifetime, it was considered that the dominant decay was into two pions (i. e., the anomaly is an enhancement in two-pion production for low energies of the two-pion systems). The charged-to-neutral ratio was 2:1, indicating a state $J = 0^+$.

The anomaly can be satisfactorily explained by a strong final-state interaction between the two pions from the reaction $p + d \rightarrow \text{He}^3 + 2\pi$. The S-wave $\pi\pi$ scattering length in the $I = 0$ state was determined as

$a_{s0} = 2 \frac{\hbar}{\mu c}$. This value, however, is accurate to within a pion Compton wave length, since its determination is dependent on the radius of interaction, which is not well known.

⁴A. Abashian, N. E. Booth, and K. M. Crowe, Rev. Mod. Phys. 33, 393 (1961); Phys. Rev. Letters 5, 258 (1960); Phys. Rev. Letters 7, 35 (1961).

⁵Alexander Abashian, Norman E. Booth, Kenneth M. Crowe, Roger E. Hill, and Ernest H. Rogers, Meson Production in $p + d$ Collisions and the $I = 0$ $\pi\pi$ Interaction. I. Measurements of the Momentum Spectra of He^3 and H^3 Nuclei Produced in High-Energy $p + d$ Collisions, UCRL-10407, Nov. 1, 1962.

THEORETICAL PHYSICS

David L. Judd in charge

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I. S-MATRIX AND ELEMENTARY-PARTICLE THEORY

The emphasis in elementary-particle physics, both experimental and theoretical, has been shifting to unstable particles and resonances. Field-theoretic approaches to these problems are clouded by questions of existence of the basic quantities. An S-matrix theory of unstable particles and resonances has been developed on the basis of rigorous Fredholm solutions of the physical unitarity equations. It is proved that the associated poles must occur at exactly the same complex energy in all S-matrix elements, and that the residue R_{ij} factorizes: $R_{ij} = R_i R_j$. This means that, for multichannel processes, the contribution of an unstable particle or resonance splits into factors depending separately on the initial and final states. Stable-particle poles factorize in this same way, and the two factors are, in this case, themselves S-matrix elements. In analogy, the individual factors for the unstable particle or resonance poles can be considered S-matrix elements for the unstable particle. These generalized S-matrix elements are well defined, but only at the precise mass value associated with the pole; no extension off the mass shell is defined. Stable and unstable particles enter, then, into S-matrix theory in a quite symmetrical manner. The theory provides a relativistic, and relatively simple, basis for the usual analysis of multichannel resonance processes by the K-matrix formalism. The usual boundary-value treatment in coordinate space is nonrelativistic and involves an ambiguous radius of the resonance region. The work was reported at the 1962 International Conference on High Energy Physics at CERN, and in Laboratory reports.^{1,2} Publication is planned. (Henry P. Stapp)

The equality of the masses and lifetimes of conjugate antiparticles has been proved by Luders and Zumino³ on the basis of CPT invariance. Their proof is not rigorous because its use of unperturbed eigenstates conflicts with the theorem of Haag⁴ and Hall and Wightman.⁵ A rigorous proof has been given in the framework of the S-matrix theory of unstable particles. The proof is based on the fact that the structure of the Fredholm denominator function is such that, for it, the CPT transformation is equivalent to antiparticle conjugation. The work was reported at the 1962 International Conference on High Energy Physics at CERN, and in a Laboratory report.² Publication is planned. (Henry P. Stapp)

¹Henry P. Stapp, Unstable Particles in S-Matrix Theory, UCRL-10259, May 23, 1962.

²Henry P. Stapp, On the Masses and Lifetimes of Unstable Particles, UCRL-10261, May 24, 1962.

³G. Luders and B. Zumino, Phys. Rev. 106 385 (1957).

⁴R. Haag, Kgl. Danske Videnskab. Selskab, Mat.-Fys. Medd. 29, no. 12 (1955).

⁵D. Hall and A. S. Wightman, Kgl. Danske Videnskab. Selskab, Mat.-Fys. Medd. 31, no. 5 (1957).

The program of developing S-matrix theory into a complete self-contained framework for elementary-particle physics has been further pursued. A formal development, following the lines sketched in an earlier work,⁶ has been partially completed. The postulates have been slightly weakened and brought closer to physically verifiable principles. A major improvement is a new S-matrix proof of the normal connection between spin and statistics. The previous one depended on a now eliminated assumption, not experimentally verified in all cases, that self-conjugate combinations of particle-antiparticle amplitudes have measurable magnitudes. The new proof has similarities to the field theoretic proof obtained recently, but is not based on conjectures involving local field operators. Parts of the work have appeared as UCRL reports.^{7, 8} A preliminary account was given as an invited paper at the 1962 New York meeting of the American Physical Society, and has now been published.⁹ A complete report is in the process of preparation. (Henry P. Stapp)

The concept of intrinsic parity has been examined from the S-matrix viewpoint. No a priori notion of particle intrinsic parity is entailed by S-matrix principles; one has rather the possibility that experimental correlations are the same in two mirror image systems. If this is the case, then for each process occurring in nature the sum over initial and final orbital quantum numbers either is even or is odd. This defines for each process an intrinsic parity, which, in principle, is experimentally observable. The relationship between the process intrinsic parities of the various processes described by a single scattering function is fixed by the analyticity requirement; the switch from initial particle to final antiparticle reverses the process intrinsic parity in the fermion case and leaves it unchanged for bosons. A corresponding result in field theory is well known. From the existence of process intrinsic parity the useful concept of particle intrinsic parity can be obtained by construction. The certain vagueness of the a priori concept introduced in field theory is avoided and well-known difficulties connected with the possibility of super selection rules are not encountered. A report of the work is shortly to appear.¹⁰ (Henry P. Stapp)

The problem of constructing invariant scalar amplitudes for the scattering of particles of arbitrary spin has been investigated in the framework of Stapp's spinor S-matrix theory. Reported results include a procedure for defining the Stapp invariant amplitudes for arbitrary spin in terms of representations of the inhomogeneous Lorentz group, the construction of projection operators for the irreducible parts of a tensor of arbitrary rank, and the development of a covariant formalism for constructing a set of basis

⁶ Henry P. Stapp, Phys. Rev. 125, 2139 (1962).

⁷ Henry P. Stapp, The Decomposition of the S Matrix and the Connection Between Spin and Statistics, UCRL-10289, June 18, 1962.

⁸ Henry P. Stapp, Coordinate Space and Position Variables in S-Matrix Theory, UCRL-10288, June 11, 1962.

⁹ Henry P. Stapp, Revs. Modern Phys. 34, 390 (July, 1962).

¹⁰ Henry P. Stapp, Intrinsic Parity from the S-Matrix Viewpoint, Phys. Rev. 28, 1963 (1962).

matrices for the S matrix, for particles of arbitrary spin.¹¹ A brief discussion of possible kinematical singularities was also given. With the assumption that scalar amplitudes satisfying the Mandelstam representation can be found, the unique continuation of the partial-wave helicity amplitudes in total angular momentum was obtained. (David N. Williams, Asim O. Barut, and Ivan Muzinich)

For two-body reactions a method of constructing scalar amplitudes having no kinematical singularities has been developed. This means that a Mandelstam representation can be used for higher spins whenever it can be used in the corresponding problem without spin. Work on the classification of the amplitudes according to space and time-inversion properties is in progress. (David N. Williams)

For problems involving arbitrary spin a generalization of the usual spin - 1/2 calculus has been developed. A question that arises here is how to construct the isotropic spinors, which are invariant symbols having the same numerical value in every frame. A complete characterization of all isotropic spinors and tensors under the homogeneous proper orthochronous Lorentz group has been given in terms of the metric tensor, $g_{\mu\nu}$, the alternating symbol, Clebsch-Gordan coefficients, and the Pauli matrices. This generalizes known results for the rotation group. (David N. Williams)

In order to construct, in S-matrix theory, invariant scalar amplitudes with useful analytic properties it is necessary to use generalizations of the Hall-Wightman theorem to regions other than the future tube. Needed generalizations have been proved. The question arises: What is the most general kind of domain for which a Hall-Wightman theorem can be proved? Necessary and sufficient conditions for a domain to have this property have been found. The theorem holds, for example, for domains with boundaries determined, in a certain sense, by scalar invariants. Work is in progress to extend the Hall-Wightman theorem to analytic functions invariant only under the proper Lorentz group, the Lorentz group without space inversion. Extension of the theorem to functions defined only on complex manifolds such as the mass shell is also being studied. (David N. Williams)

It has been shown earlier that the analytic structure of perturbation theory described by the Landau-Cutkosky rules is in fact more general than its origin suggests, and is characteristic of a very wide class of unitary theories. Dr. Stapp has independently been investigating this problem and our work has much in common. A question that arises in this work is to what extent it is necessary to make continuations in the external masses in order to establish an identity of physical-sheet properties between perturbation theory and any unitary theory. This had seemed necessary in order to establish the existence of anomalous thresholds. However, investigation shows that, at least for certain cases, the interlocking structure of unitary singularities ensures that an "unconventional" choice of anomalous threshold singularities would result in the necessary occurrence of unwanted complex singularities. The result indicates a way to avoid analytic continuation in the external masses, which is disagreeable in an S-matrix theory. The work is being published.¹²

¹¹A. O. Barut, I. Muzinich, and D. N. Williams, Construction of Invariant Scattering Amplitudes for Arbitrary Spins and Analytic Continuation in Total Angular Momentum (UCRL-10463, September 11, 1962), to be submitted to Phys. Rev.

¹²John Polkinghorne, Anomalous Thresholds in Unitary Theories, Phys. Rev., Dec. 1, 1962.

Investigations have been made relating to recently published papers by Henry P. Stapp on S-matrix theory. The connection between the iterations of the equation for M functions, derived by Stapp from the unitarity condition, and renormalized perturbation theory have been examined. Also, attempts have been made to relate Stapp's formulation of S-matrix theory of unstable particles to specific simple cases in potential theory. (John Hutchins)

A study of the Stapp formalism in dispersion theory was carried out. Calculations were made to study the relationship of this formalism to the field-theoretic perturbation scheme and to the field-theoretic expression by Jacob and Sachs for the lifetime of an unstable particle. In connection with these calculations, a study was also made of the analytic properties of the field-theoretic perturbation expansion. (Alexander Maksymowicz)

Work has been done in the general area of relativistic S-matrix theory. The work is described in three reports.¹³⁻¹⁵ (Asim O. Barut)

Two-particle scattering amplitudes are known to have a natural boundary along the negative real axis on the second sheet. Yet the individual partial-wave amplitudes are known to have no such boundary. This apparent anomaly has been examined and the way in which the natural boundary is "erased" by the partial-wave integration has been explicitly demonstrated. (Jack Wong)

An investigation of mechanism of the "boot strap" type, both in field theory and in S-matrix theory, was continued. In field theory the fact that such solutions need not have the symmetry of the Lagrangian leads to difficulties, and some provisional attempts to avoid these difficulties have been made. (Jeffrey Goldstone)

At the suggestion of Dr. Malvin A. Ruderman, work was started on extending a theory due to F. E. Low on the distinction between elementary particles and bound states.¹⁶ Low's model consists of two particles involved in scattering in the static approximation. He shows that one cannot distinguish between the cases in which the two particles form a bound state or in which an elementary particle is connected with them in a trilinear vertex. It is desirable to extend the theory to include more particles and to make it relativistically invariant. In this direction, it has been shown that the Low model admits no more than one bound state and that the symmetry between elementary particle and bound state, in this model, is due to the initially assumed crossing symmetry. By investigating the Mandelstam representation of the scattering amplitude, which incorporates relativistic invariance and crossing symmetry, there is reason to hope that a more general model can be constructed. No results have yet been obtained. The Lee model has also been critically examined with respect to the bound-state-elementary-particle symmetry. (James H. Crichton)

¹³ A. O. Barut and D. Zwanziger, Phys. Rev. 127, 974 (1962).

¹⁴ A. O. Barut and F. Calogero, Singularities of the Scattering Amplitude for a Class of Soluble Potentials, Phys. Rev. (in press).

¹⁵ A. O. Barut, Analyticity in Angular Momentum of the Many-Channel S Matrix from Dispersion Relations and Unitarity, Phys. Rev. (to be published).

¹⁶ F. E. Low, Nuovo Cimento 25, 678 (1962).

Under the direction of Dr. Weinberg the problem of composite particles vs. elementary particles is being examined both within the framework of the nonrelativistic Schrödinger equation and in field theory, the latter by means of the Bethe-Salpeter equation. The Born series for the S matrix diverges at a certain energy, because of the pole in the amplitude at a bound-state energy. The procedure adopted is to remove this natural divergence by "subtracting out" of the Fredholm kernel the bound-state parts by the Schmidt method or, in the nonrelativistic case, by subtractions of certain potentials. If "proper" subtractions are made, then the Born series for the scattering amplitude converges. The method, if it can be perfected, should provide fundamental insight into the relations between bound states and elementary particles, and may lead to practical methods of calculation in field theory. (Michael Scadron)

A model in which the photon is regarded as a bound state of a positron-electron pair is being investigated. The one-photon exchange supplied the attractive force. In the Born approximation to quantum electrodynamics this leads to a divergence of the integral over the left-hand cut in a N/D calculation. The infrared divergence may be removed by giving the photon a small mass. The ultraviolet divergence is removed by considering the photon to be a Regge pole in the amplitude, which supplies a cutoff related to the slope of the photon trajectory in the plot of J vs s . Another parameter is the derivative of the effective coupling constant with respect to energy squared. With these two parameters it is hoped to fit the zero mass of the photon and the fine-structure constant. A pilot calculation in which the spin of the electron is ignored is being performed with the assistance of Mr. Larry Tribe, who is programming the calculations for the IBM 7090. This work is still in progress. (John M. Charap and Euan J. Squires)

II. COMPLEX ANGULAR MOMENTUM, REGGE POLES, AND DISPERSION RELATIONS

During the past year there has been rapid and exciting progress in the theory of strong interactions based on the S matrix. The major development was recognition of the importance of continuation in angular momentum and of poles in the complex angular momentum plane (Regge poles). The Theoretical Group at Berkeley has been active in following up this breakthrough, and my main concern has been to encourage and correlate the various aspects of "Reggeology" being studied locally. Otherwise, my chief contribution has been to point out, together with Frautschi, that when all experimental data--for both high and low energies--are examined from the point of view of Regge poles, it becomes plausible that the entire spectrum of strongly interacting particles and their interactions may emerge from simple assumptions about the S matrix. There should be no arbitrary parameters allowed. Recently I have developed a new set of S-matrix equations in order to check this conjecture. Publications during this period are listed below.¹⁻⁶ (Geoffrey F. Chew)

The study of Regge poles was continued, and the role they play in determining the behavior of high-energy cross sections recognized. In terms of Regge poles one can understand and correlate the rates at which various high-energy cross sections approach their constant limit.⁷ A detailed numerical analysis of the available data on high-energy total cross sections of $\pi^{\pm}p$, $K^{\pm}p$, pp , $p\bar{p}$, np was carried out. This showed that although it was possible to fix the values of $a_p(0)$, $a_{\omega}(0)$, the value of $a_{\rho}(0)$ could be determined only with a large degree of uncertainty from the presently available data. (Bhalchandra M. Udgaonkar)

The nucleon-nucleon problem was considered from the standpoint of analyticity in angular momentum. The Regge poles with the quantum numbers of the nucleon-antinucleon channel control the high-momentum transfer behavior of the nucleon-antinucleon amplitude and hence, by crossing, the high-energy behavior of the nucleon-nucleon amplitude. A detailed analysis of the high-energy nucleon-nucleon amplitude was performed by use of the Regge-pole hypothesis. In particular the contribution of the π and ρ mesons was considered in some detail. This work has been described in a paper submitted for publication.⁸ (Ivan Muzinich)

¹G. F. Chew and S. Frautschi, Phys. Rev. Letters 8, 41 (1962).

²G. F. Chew, Rev. Mod. Phys. 34, 394 (1962).

³G. F. Chew, Phys. Rev. Letters 9, 233 (1962).

⁴G. F. Chew, Strong Interaction Theory without Elementary Particles, in Proceedings of the 1962 International Conference on High Energy Physics, CERN, p.525.

⁵G. F. Chew, The Self-Consistent S Matrix with Regge Asymptotic Behavior, Phys. Rev. (to be published).

⁶G. F. Chew, The Artificial Singularity in the N/D Equations of the New Strip Approximation, DAMTP preprint, Cambridge University.

⁷B. M. Udgaonkar, Phys. Rev. Letters 8, 142 (1962).

⁸I. Muzinich, High-Energy Nucleon-Nucleon Scattering (UCRL-10331, June 26, 1962), submitted to Phys. Rev.

A detailed investigation of the problem of analytic continuation in angular momentum of the scattering amplitude for many-channel potential-scattering problems with spin has been carried through. This included a general proof of the factorizability of the residues of Regge poles, valid for the many-channel potential-scattering problem. This proof can, under certain reasonable assumptions, be extended to relativistic S-matrix theory. The work has been submitted for publication.⁹ A continuation of the S matrix for many-channel potential-scattering problems with arbitrary spin, away from the physical values of the angular momentum, was defined. The scattering amplitude was expressed as a sum over physical J values of a summand meromorphic on the entire J plane. It was then proved possible to make a generalized Sommerfeld-Watson transformation on this partial-wave sum. On the basis of an important symmetry proved for the partial-wave amplitudes, it was also shown possible to perform a modification of the Sommerfeld-Watson transformation analogous to that of Mandelstam. A pole of the S matrix at $J = \alpha$ was shown to be associated with a contribution to the scattering amplitude which, for large values of $z = \cos \theta$, behaves like z^α . Exchange potentials and the generalization of J parity were also discussed. The work has been submitted for publication.¹⁰ (John M. Charap and Euan J. Squires)

A study of nucleon-nucleus scattering, as dominated by the Pomeranchuk Regge pole at high energies, showed that the very-high-energy nucleon-nucleus cross section should be proportional to A instead of to $A^{2/3}$, as had been thought. The rate at which this limit is expected to be reached was calculated on the basis of a simple model. This also indicated the possible existence of a cut in the angular momentum plane for this problem, in which one has an anomalous threshold. The work has been published.¹¹ (B. M. Udgaonkar)

A study of the Regge poles for Coulomb scattering amplitudes was made. It was shown that the amplitude is a meromorphic function in the entire J plane. This work has been published.¹² (Virendra Singh)

Problems associated with the continuation of partial-wave scattering amplitudes to complex values of the angular momentum have been considered. It has been shown that the conditions set on the amplitude for large values of the angular momentum by the requirement that it be useful in practical applications effectively define the continuation uniquely. Some properties of this continuation for nonrelativistic potential scattering, and for a relativistic amplitude satisfying the Mandelstam representation, have been obtained. The work has been published.¹³ (Euan J. Squires)

⁹John M. Charap, Elihu Lubkin, and Antonio Scotti, Theory of Nucleon-Nucleon Scattering on the Strip Approximation to the Mandelstam Representation (UCRL-10028, December 19, 1961), submitted to Ann. Phys.

¹⁰John M. Charap and Euan J. Squires, On Complex Angular Momentum in Many-Channel Potential Scattering Problems, I and II (UCRL-10138, March 22, 1962, and UCRL-10209, May 3, 1962), submitted (in two parts) to Ann. Phys.

¹¹B. M. Udgaonkar and M. Gell-Mann, Phys. Rev. Letters 8, 346 (1962).

¹²Virendra Singh, Phys. Rev. 127, 632 (1962).

¹³Euan J. Squires, Nuovo Cimento 25, 242 (1962).

A study has been made of the effect of the requirement of unitarity in crossed channels on the behavior of scattering amplitudes in the Regge plane. This is a characteristic of relativistic theories not found in potential theory. A consideration of the elastic term of the unitary sum showed that this term would have many singularities in addition to the Regge poles. Similar singularities have been shown to occur for an arbitrary term in the unitary sum. Moreover, each term gives an identical set of singularities. This means that no firm conclusion can be drawn, from these considerations, about the behavior of the complete amplitude, since there is a possibility of cancellations. The result is of interest as it shows that an assumption of pure pole singularities in the Regge plane is not necessarily false in a full relativistic theory. This work is described in a paper submitted for publication.¹⁴ (John Polkinghorne)

Other problems that have been investigated, but on which work is incomplete, are certain special cases of second-type singularities of scattering amplitudes, the high-energy behavior of perturbation theory, and a means of finding in a relativistic theory the cuts in the Regge plane that Udgaonkar and Gell-Mann have suggested, on the basis of impulse-approximation calculations, should exist for the scattering of composite systems. (John Polkinghorne)

An investigation was undertaken of Regge trajectories for potential scattering.¹⁵ Numerical results were obtained for single attractive and repulsive Yukawa potentials. The IBM 7090 code used for the majority of this work has been generalized to treat any analytic potential, and is available.¹⁶ (Akbar Amadzadeh, Philip G. Burke, and Cecil Tate)

¹⁴ John Polkinghorne, Complex Angular Momenta and Unitarity in Crossed Channels (UCRL-10353, July 6, 1962), submitted to Phys. Rev.

¹⁵ A. Ahmadzadeh, P. G. Burke, and C. Tate, Regge Trajectories for a Single Attractive Yukawa Potential (UCRL-10140, March 1962); A. Ahmadzadeh, P. G. Burke, and C. Tate, Regge Trajectories for Yukawa Potentials (UCRL-10216, May 1962), submitted 1962 International Conference on High Energy Physics (Geneva, July 1962).

¹⁶ Philip G. Burke and Cecil Tate, FORTRAN program called TREGGE to calculate Regge trajectories and S-matrix elements for an arbitrary potential, UCRL-10384, July 24, 1962.

Regge trajectories have been calculated for relativistic scattering.¹⁷ The results imply that the methods adopted can be used to calculate physically significant cross sections by use of the Mandelstam representation. Certain associated FORTRAN subroutines have been written and are available.¹⁸ (Philip G. Burke and Cecil Tate)

A general method has been developed to approximate the Regge trajectories in the relativistic case. By writing a once-subtracted dispersion relation for the real part $\text{Re}a(t)$ and using the known properties of $\text{Im}a(t)$ and $\text{Re}a(t)$, it has been possible to derive $\text{Re}a(t)$, using a plausible assumption for $\text{Im}a(t)$. The method has been applied to the nucleon Regge trajectory and the physical implications discussed. The same method can be applied to any Regge trajectory, the accuracy of the approximation depending on the experimental knowledge about it. Currently the method is being applied to the Pomeranchuk trajectory. (Ismail Sakmar and Akbar Ahmadzadeh)

The kaon-nucleon high-energy scattering has been investigated from the Regge pole viewpoint. Appropriate partial-wave amplitudes have been defined and analytically continued into the complex angular momentum J plane. Regge-pole contributions to the three different channels of the problem, which mutually control the forward and backward scattering of one another, have been investigated and the quantum numbers for Regge trajectories determined. The effects of the exchanged particles on KN and $\bar{K}N$ scattering have been studied, with emphasis on the different behaviors in these two channels of the backward-scattering amplitudes. Work is in progress on the isotopic spin aspects, the crossing relations, and the dynamics of the problem. (Ismail Sakmar)

An investigation was made of the analyticity in complex angular momentum plane of the various partial-wave amplitudes occurring in πN scattering and in the crossed $2\pi \rightarrow N\bar{N}$ channel. The notion of J parity is clarified by considering nonconservation. It was found that, corresponding to a Regge pole in πN scattering channel, $J = \alpha(W)$, there is also a Regge pole at $J = \alpha(-W)$, W being c.m. energy in the πN scattering channel. The observed particle and resonance states in the two channels are discussed from the Regge point of view. Also, the expression for high-energy backward and forward pion-proton scattering are given. A paper has been written describing the work.¹⁹ (Virendra Singh)

A program of calculating the nucleon mass and the position of the $3/2-3/2$ resonance of the πN system by means of a reciprocal bootstrap mechanism was initiated. The work is still in progress. (Virendra Singh and Bhalchandra M. Udgaonkar)

¹⁷ Philip G. Burke and Cecil Tate, Calculation of Regge Trajectories by Using Dispersion Relations (UCRL-10217. Submitted 1962 Conference on High Energy Physics (Geneva, July 1962).

¹⁸ Philip G. Burke and Cecil Tate, Routines B1-EO-TANZ, C3-EO-BESL, C3-EO-GAMMA, C3-EO-HYPR, C3-EO-LEGN.

¹⁹ Virendra Singh, Regge Poles in the πN Scattering and $\pi + \pi \rightarrow N + \bar{N}$ (UCRL-10416, August 7, 1962), submitted to Phys. Rev.

Dynamical $\pi\pi$ equations have been set up for partial-wave amplitudes (in particular for the $I = 1$ $l = 1$ amplitude). The input parameters are estimates from experiment of the slopes and values of the residues and positions of Regge poles in cross channels. The equations used are those outlined by Chew.²⁰ The program will, at least in its first stages, be semiphenomenological rather than bootstrap. Calculations are being made on the IBM 7090. (C. Edward Jones)

The 2π contribution to the electromagnetic structure of the nucleon has been recalculated by a new method for evaluating the left-hand cut of the Frazer-Fulco amplitudes. Excellent agreement with experimental data was obtained by using the experimental values for the position and the width of the ρ meson. The work has been reported.²¹ (Virendra Singh and Bhalchandra M. Udgaonkar)

The nucleon-nucleon scattering amplitude was examined within the framework of the strip approximation. Asymptotic bounds to the behavior of the scalar amplitudes were derived and were applied to limit the number of "allowed" single spectral functions to six, and correspondingly to limit the types of dynamically independent one-particle states. The unitarity equations in which only two-particle intermediate states were retained were explicitly derived for both the NN and $N\bar{N}$ channels. The $N\bar{N}$ equations express a portion of the double spectral functions in terms of the πN amplitudes. The NN equations express another portion of these functions through coupled integral equations. The work has been submitted for publications.²² (John M. Charap, Elihu Lubkin, and Antonio Scotti)

Formulas have been derived for the NN two-pion exchange potential, using the strip approximation, and the numerical calculation of this potential initiated. Some experimental consequences of the assumption that the nucleon is a πN bound state have been investigated, and the results reported.²³ Several calculations were made in low-energy $\pi\pi$ scattering, using a combination of the Chew-Mandelstam and generalized Ball-Wong techniques with self-consistency. Most of the results of these calculations have been reported.^{24, 25} (Louis Balázs)

²⁰G. F. Chew, The Self-Consistent S-Matrix with Regge Asymptotic Behavior, CERN preprint.

²¹V. Singh and B. M. Udgaonkar, Vector Charge and Magnetic Moment Form Factors of the Nucleon (UCRL-10264, May 25, 1962), (to be published).

²²John M. Charap, Elihu Lubkin, and Antonio Scotti, Theory of Nucleon-Nucleon Scattering on the Strip Approximation to the Mandelstam Representation (UCRL-10028, December 19, 1961), submitted to Ann. Phys.

²³Louis Balázs, The $I = \frac{1}{2}$, $J = \frac{1}{2}$ State in π -N Scattering with the Nucleon as a Bound State (UCRL-10026, January 19, 1962), Phys. Rev. (to be published).

²⁴Louis Balázs, Low-Energy Pion-Pion Scattering. Part I (UCRL-10157, March 28, 1962), Phys. Rev. (to be published).

²⁵Louis Balázs, Low-Energy Pion-Pion Scattering. Part II (UCRL-10376, July 23, 1962), submitted to Phys. Rev.

The $\pi\Lambda$ system is being studied in the resonance approximation, using the bootstrap mechanism of Balázs. Numerical calculations are in progress. (Michael Der Sarkissian)

An unsubtracted dispersion relation for the isovector kaon form factor may be written in terms of the $\pi\pi \rightarrow K\bar{K}$, $J = 1$, $I = 1$ scattering amplitude B and the pion form factor. The B may be calculated by writing a dispersion relation for the function $\Gamma = BD$, where D is the denominator function for the $J = 1$, $I = 1$ $\pi\pi$ -scattering amplitude. The integral over the left-hand cut in Γ has been evaluated in the kernel approximation first used by Balázs,¹ which yields a two-pole expression for Γ . The residues of the poles were determined by matching at two points the amplitude continued analytically from the crossed channels. In these only the K^* resonance was retained. The possibilities of spin-0 and spin-1 assignments to this resonance were studied, and it was shown that only the spin-1 assignment gives rise to the correct order of magnitude for the contribution to the isovector kaon charge. This work has been prepared for publication.²⁶
(Alberto Pignotti)

A self-consistent calculation of the K^* resonance has been attempted. The N/D method was used, and the kernel approximation due to Balázs²⁴ was invoked. The forces introduced are the exchange of the K^* in the u channel and the exchange of the ρ and the "Pomeranchon" in the t channel. The "coupling" of these unstable particles to the $K\bar{K}$ system is calculated by solving the equations for the corresponding $\pi\pi \rightarrow K\bar{K}$ partial waves. The only free parameters left are the pion mass, which sets the mass scale, and the kaon, ρ , and "Pomeranchon" masses. Numerical calculations are in progress. (Alberto Pignotti)

²⁶ Alberto Pignotti, The K^* Spin and the Isovector Kaon Charge (UCRL-10467, September 12, 1962), submitted to Phys. Rev. Letters.

III. LEPTON PHYSICS

A previously developed theory of weak interactions¹ has been extended to include the neutrino interaction. The following ratios of cross sections are predicted:

$$\begin{aligned}
 & (\nu + n \rightarrow p + \mu^-) : (\nu + n \rightarrow p + e^-) : (\nu + n \rightarrow \Sigma^+ + \mu^-) : (\nu + n \rightarrow \Sigma^+ + e^-) \\
 & \approx \begin{cases} 1 : 0 : \eta^2/4 : \delta^2 \eta^2/4 & (\text{for } \nu \text{ from } \pi \rightarrow \mu \text{ decays}) \\ 1 : \delta^2/4 : \delta^2 \eta^2/4 : 0 & (\text{for } \nu \text{ from } K \rightarrow \mu \text{ decays}) \end{cases}
 \end{aligned}$$

Here $\delta^2 \approx 1/10$ and $\eta^2 \approx 1/10$. (Gyo Takeda)

The possibility of intermediate vector bosons¹ being produced much more copiously than usually estimated has been examined. This is shown to be possible if (a) there are two kinds of vector bosons, one being responsible for the leptonic decays of elementary particles and the other for the nonleptonic decays, and (b) the coupling constants between the vector field and the currents are different for the $\Delta S = 0$ currents and $\Delta S \neq 0$ currents. The possibility of some of the observed resonances such as K^* ($M_{K^*} \approx 730$ MeV) has been examined. (Gyo Takeda)

The neutrino beam intensity to be expected from high-energy accelerators has been calculated. The neutrinos are the result of the decay of pions and kaons produced by proton bombardment of an external target. The empirical Perkins formula has been used for the spectra of pions and bosons, and the isotropic neutrino spectrum in the pion rest system has been transformed to the laboratory system. (Joseph Lepore and Robert J. Riddell, Jr.)

At the suggestion of Professor Malvin A. Ruderman, the effect of the possible existence of a first-order $(e\nu)$ $(e\nu)$ coupling on the neutrino-pair emission rate by a hot, partially degenerate relativistic plasma was investigated. Calculations were made for temperatures and densities relevant for certain stages of stellar evolution. Neutrino-pair emission by collective electron modes, especially transverse plasma excitations, is found to be the main mechanism for neutrino radiation by a dense stellar plasma, when e^-e^+ production is small either because the temperature is too low ($T \leq 10^8$ °K) or because degeneracy suppresses it. The neutrino luminosity of a star can greatly exceed its photon luminosity for a central core temperature $> 10^8$ °K. The results have been reported.² (C. H. Woo)

Work has continued on the attempt to understand the transition paths taken by a μ^- meson captured in solid lithium. The wave functions of the μ^- -mesonic atom of the solid were obtained by means of perturbation theory and numerical integration with the IBM 704. The energy dependence of the various transition rates such as radiation rate, Auger rate involving the core electrons, and Auger rate involving the band electrons were obtained through analytic methods and by numerical calculations on the IBM 704. Matrix elements involving μ^- -mesonic coordinates also were obtained. The various approximations used have been examined. (Coates Johnson)

¹G. Takeda, Ann. Phys. 18, 310 (1962).

²J. Barclay Adams, Malvin A. Ruderman, and Ching-Hung Woo, Neutrino Pair Emission by a Stellar Plasma (UCRL-10343, July 2, 1962), submitted to Phys. Rev.

IV. NUCLEAR THEORY

Calculations have been made over large regions of the Nuclear Periodic Table to determine the deformation of and the energy difference between spherical and deformed nuclei as functions of neutron and proton numbers. These calculations involve minimizing the sums of S. G. Nilsson's single-particle energies as functions of deformations without pairing. Extended regions of deformed nuclei occur for the very-neutron-deficient rare earths and for neutron-deficient actinides. Experiments are suggested for the observation of deformation in these regions of the Nuclear Periodic Table and, also, for other more limited regions. The work was done in collaboration with Eugene Marshalek of the University Institute for Theoretical Physics at Copenhagen and Raymond K. Sheline of Florida State University. (Lucy Wu Person)

Work was continued on the model in which fission fragments are represented by idealized charged liquid drops constrained to spheroidal shapes. A study of the dynamics of the separation of completely symmetrical drops was made by using an IBM 7090 computer to integrate the classical equations of motion. For this restricted case it was found that the final translational kinetic energy is approximately related in a very simple way to the initial conditions. By use of a distribution of initial conditions determined by assuming statistical equilibrium at the saddle point, a formula for the translational kinetic energy distribution was derived. Various generalizations to more realistic asymmetric cases are now in progress. (James Rayford Nix)

Quantitative results on the properties of saddle-point shapes of nuclei, idealized as charged liquid drops, have been reported.¹ The work was done in collaboration with Stanley Cohen of the Argonne National Laboratory. (Wladyslaw J. Swiatecki)

The IBM 7090 code used in the above study has been generalized to include the effect of rotation, and the various families of equilibrium of a rotating charged drop are being tabulated as functions of the two parameters in the problem, the charge on the drop and its angular momentum. The existence of nonaxially symmetric configurations of equilibrium of a drop are predicted provided the charge is not too high and the angular momentum is between a lower and an upper limit, both of which appear in general to be accessible in bombardments of nuclei with heavy ions. The work was done in collaboration with S. Cohen of the Argonne National Laboratory and Franz Plasil of the Chemistry Division. (Wladyslaw J. Swiatecki)

The second part of the analysis of the time-of-flight experiment on fission fragments and neutrons from Cf²⁵² has been reported.² The work was done in collaboration with Harry R. Bowman, J. C. D. Milton, and Stanley G. Thompson of the Chemistry Division. (Wladyslaw J. Swiatecki)

¹W. J. Swiatecki, The Deformation Energy of a Charged Drop: Part V: Results of Electronic Computer Studies (UCRL-10450, Aug. 1962), submitted to Ann. Phys.

²W. J. Swiatecki, Further Studies of the Prompt Neutrons from the Spontaneous Fission of Cf²⁵² (UCRL-10139, Apr. 1962), submitted to Phys. Rev.

The anomalous behavior of the number of neutrons emitted by fission fragments of different masses has been discussed in terms of the optimum configuration of the fragments (idealized as two spheroids in close proximity) at the moment of division. An attempt was made to estimate the influence of shell effect on the fragment shapes, and a semiquantitative account of the pattern of neutron emission appears possible. The work was done in collaboration with J. C. D. Milton of the Chemistry Division and Chalk River, Canada. (Wladyslaw J. Swiatecki)

A mass formula that includes shell corrections was derived on the basis of simple theoretical considerations of a Fermi gas whose energy levels are "bunched" in an empirical way to reproduce the special stability of magic numbers of nucleons. By assuming the bunching to be associated with the spherical symmetry of the nucleus and to disappear when the nucleus is sufficiently distorted, one obtains an expression for the mass of a nucleus as function of its neutron and proton numbers, and of its shape. In its simplest version the formula has three adjustable parameters to describe shell effects. With its aid it is possible to reproduce the general behavior of shell oscillations as functions of N and Z and to account for the appearance of large ground-state deformations of nuclei in certain parts of the periodic table. This work was reported at the "Discussion on Nuclear Chemistry" held at Oxford, England in September 1962. (Wladyslaw J. Swiatecki)

V. ATOMIC PHYSICS

Work was continued and completed, with Kenneth Smith of the Argonne National Laboratory, on a review article covering theoretical and experimental aspects of the low-energy scattering of electrons and positrons by hydrogen atoms.¹ (Philip G. Burke)

Numerical results have been obtained for the elastic and inelastic scattering of electrons and positrons by hydrogen atoms between 11.00 and 54.4 eV.² The significant feature of the work is the disagreement with experiment for the 1s-2s and 1s-2p excitation cross sections by electrons. This is possibly attributable to the normalization difficulties associated with the experiment. (Philip G. Burke)

The generalized optical-potential method has been applied to the elastic scattering of electrons by hydrogen atoms for energies below the second quantum level (10.2 eV), with 1s, 2s, and 2p atomic states in the close-coupling scheme. The resulting set of coupled integrodifferential equations was numerically integrated on an IBM 7090 computer, yielding phase shifts in various spin and angular momentum states. Comparison with other theoretical predictions and available experimental data gives information on the importance of various physical effects on the scattering. Very narrow resonance-type effects in phase shifts of various spin and angular momentum states were found at energies slightly below the second quantum level. Their origin was examined. The triplet results are much better than the corresponding singlet results, in general. This seems to be due to a better provision for the Coulomb repulsion in the triplet trial wave function. Based on this conjecture, a modified form for the singlet wave function has been proposed. (Robert Pu)

The elastic scattering of an electron from a neutral hydrogen atom in the ground state has been studied. A variational method gives the phase shift of the scattered wave and the wave function of the system. Numerical calculations are currently under way on an IBM 7090 computer. (Robert L. Armstead)

An attempt is being made to obtain the radiative corrections to energy levels in a strong Coulomb field. Relatively precise measurements of the x-ray fine structure have been obtained by Shacklett and DuMond.³ The screening effects have been quite difficult to take into account but, as observed by Schawlow and Townes,⁴ these effects should give very nearly,

¹P. G. Burke and Kenneth Smith, *The Low-Energy Scattering of Electrons and Positrons by Hydrogen Atoms*, *Rev. Mod. Phys.*, to be published July 1962).

²P. G. Burke, H. M. Schey, and Kenneth Smith, *Collisions of Slow Electrons and Positrons with Atomic Hydrogen*, to be submitted to *Phys. Rev.*

³R. L. Shacklett and J. DuMond, *Phys. Rev.* 106, 501 (1957).

⁴A. L. Schawlow and Townes, *Phys. Rev.* 100, 1273 (1955).

equivalent corrections to the $2^2P_{1/2}$ and the $2^2P_{3/2}$ levels. There is thus some hope of a consistency check if the radiative corrections can be correctly done. Initially, expansion of the Coulomb Green's function in angular momentum eigenstates similar to that used by Brown, Schaeffer, and Langer was undertaken and the radial Green's function of Kroll and Wichmann⁶ used. But the radial integrals have proven intractable. Currently the variational method developed by Schwartz and Tiemann⁷ is being applied to the problem. The results are encouraging and it is hoped that definite conclusions will soon be forthcoming. (Michael M. Austin)

An investigation has been made of the applicability of many-body perturbation theory in calculating electron correlations in atoms. It was found that, in order to obtain results that agree well with experiment, certain classes of diagrams, representing terms of the perturbation series, must be included to many orders. The higher-order diagrams were found to be more important in calculating correlations among the outer electrons than among inner electrons. Methods for summing various classes of these diagrams were found. Diagrams in which the exclusion principle is violated in intermediate states were found to be of particular importance. The total correlation energy in beryllium was calculated by perturbation theory, with an IBM 7090 computer. The result is -2.48 ± 0.11 eV. The value obtained from experiment is -2.59 eV. The calculated correlation energies for the different electronic shells were found to be -1.19 eV among 2s electrons, -1.15 eV among 1s electrons, and -0.135 eV between the 1s and 2s shells. This work has been reported.⁸ (Hugh P. Kelly)

The random-phase approximation, useful for studies of the infinite electron gas and nuclear structure, has been applied to atomic structure. Excitation energies, oscillator strengths, and photo-ionization cross sections were computed for the $1P^0$ states of beryllium, magnesium, calcium, zinc, and strontium. It was found that the values of the lowest excitation energy, and the corresponding oscillator strength, were substantially improved in the calculation by random-phase approximation over the bare Hartree or Thomas-Fermi values. The photoionization cross sections near threshold were greatly increased over the bare values, except for beryllium. This increase, needed to explain the experimental results for strontium, appears also for magnesium and calcium. The disagreement with experiment for magnesium and calcium is probably due to auto-ionization effects not included in the theory. (Philip L. Altick)

⁵G. E. Brown and G. W. Schaefer, Proc. Roy. Soc. (London) A233, 537 (1956); G. E. Brown, G. W. Schaefer, and J. S. Langer, Proc. Roy. Soc. (London) A251, 92 (1959); G. E. Brown and D. F. Mayers, Proc. Roy. Soc. (London) A251, 105 (1959).

⁶N. Kroll and E. Wichmann, Phys. Rev. 101, 843 (1956).

⁷C. Schwartz, Ann. Phys. 6, 156 (1959); 6, 170 (1959); C. Schwartz and J. J. Tiemann, Ann. Phys. 2, 178 (1959); C. Schwartz, Phys. Rev. 123, 1700 (1961).

⁸Hugh P. Kelly, Correlation Effects in Atoms, UCRL-10471, October 8, 1962.

VI. PLASMA PHYSICS

A review of adiabatic charged-particle motion written in 1960 has been revised and put in a form suitable for publication as a monograph.¹ Further applications of the theory have been included. There is now a section on plasma stability via the first two adiabatic invariants. A section has also been added in which Fermi acceleration is presented in terms of present-day adiabatic theory. (Theodore G. Northrop)

Work continues in kinetic theory of plasmas, particularly the scattering of light by a plasma. The question is whether interferometer techniques with the scattered radiation can be usefully employed. (Theodore G. Northrop)

The energy transfer between a photon and a plasma has been investigated, with particular concern for the influence of cooperative effects in the plasma upon the rate of energy transfer. The problem has been reduced--in good approximation--to a quadrature. The evaluation of the expression is still in progress. (John Stack and Andrew M. Sessler)

The interaction of radiation with a plasma has been studied, with emphasis given to nonequilibrium behavior. The work is described in reports² and is still in progress. (Robert J. Riddell and Andrew M. Sessler)

The Helmholtz instability of two compressible fluids of equal density and infinite conductivity permeated by a uniform magnetic field parallel to the fluid velocity has been investigated by a normal-mode analysis. Stability against perturbations uniform in the direction parallel to the fluid-fluid interface and perpendicular to the fluid velocity was found for

$$s^2/a^2 > \left[a^2 - (v^2 - a^2)^2 \right] / \left[a^2 + (v^2 - a^2)^2 \right],$$

where the fluid velocities are $\pm v$, s is the Alfvén speed, and a the sound speed. The configuration is less stable against more general perturbations, but a general stability condition has not been obtained. (Alan Macmahon)

Northrop's analysis of the Helmholtz instability of the interface between a plasma flowing across a magnetic field and a vacuum³ has been reviewed and an inconsistency in his perturbation amplitudes resolved. His vacuum electric field amplitudes were found to be missing terms corresponding to the displacement of the unperturbed surface charge from its equilibrium position. (Alan Macmahon)

¹T. G. Northrop, The Adiabatic Motion of Charged Particles, to be published by John Wiley and Sons in 1963.

²R. J. Riddell and A. M. Sessler, COT-62-42; COT-62-43; COT-62-44; COT-62-45 (1962).

³T. G. Northrop, Phys. Rev. 103, 1150 (1956).

A study of electromagnetic waves in nonuniform plasma is in progress. It includes a particular study of the plasma in the cylindrical geometry of Hothouse II. In Hothouse II, the axial magnetic field decreases with axial distance to a magnetic beach. Effects of Hall current, finite electron mass, and conductivity are retained in a two-fluid model at zero pressure. Retention of these effects in a cylindrical geometry leads to a fourth-order differential equation for the wave fields. The behavior of the wave fields away from the beach, and the energy transmission, reflection, and absorption by the beach will be calculated by asymptotic expansion of solutions of the fourth-order scalar differential equation. Previous workers in this field have omitted various effects in order to reduce the wave field equation to two second-order differential equations which are uncoupled or weakly coupled.⁴
(David L. Sachs)

The stability of a mirror machine with conducting end plates was examined by means of the hydromagnetic energy principle. A stability criterion, valid for arbitrary β and for arbitrary curvature of the lines of force, was derived. Current investigations concern evaluation of the stability of a mirror machine with conducting end plates by means of the nonadiabatic energy principle. (Shalom Fisher)

To obtain the contributions to the thermodynamic functions of a quantum plasma from the generalized second virial coefficient--i.e., two-body scattering effects from the temperature-dependent effective potential reflecting the polarization of the medium--it is possible to perform an expansion about the classical limit. Calculations to complete the results of this expansion are now being undertaken. An integral equation for the summation of all classes of diagrams from the perturbation expansion of this generalized second virial coefficient has been obtained. Bound-state contributions are formally included. Calculations using this equation will be started in the near future by H. E. DeWitt and others. (Sidney Putnam)

⁴T. H. Stix, Phys. Fluids 3, 19 (1960).

VII. LIQUID HELIUM

The properties of liquid He³ near the absolute zero are being studied from a microscopic point of view by employing the powerful new techniques of the Green's-function formulation of the many-body problem. The molecular interaction of He³ atoms has been fitted (via digital computation) with separable potentials, which should afford a significant simplification in the subsequent parts of the calculation. A first approximation to the ground-state properties of the system is being computed, with better approximations to the thermodynamic behavior planned for the future. (Donald Beck and Andrew M. Sessler)

The Green's-function formulation of transport properties in the many-body problem has been studied, and the method applied to the calculation of the thermal conductivity, specific heat, and self-diffusion coefficients of liquid He³. The Landau phenomenological theory is derived in the limit of very low temperatures, and deviations from this theory for higher temperatures are now under investigation. (Chi-Ching Sung and Andrew M. Sessler)

Continued study of the properties of liquid He³ has led to the definition of a number of problems which are either presently under investigation or planned for investigation in the future. The present state of knowledge of the substance is reviewed in a Laboratory report.¹ (Andrew M. Sessler)

¹A. M. Sessler, Helium Three, UCRL-10465, September 11, 1962.

VIII. PARTICLE ORBIT THEORY AND ACCELERATOR DESIGN PROBLEMS

A theoretical study of the aberrations of quadrupole magnets has been in progress for some time. An IBM 7090 program has been completed which calculates the first-order optical properties of any beam system, calculates all aberrations through third order of a beam system consisting of quadrupole and octupole magnets, and calculates the tolerances in various physical properties and in alignment of the quadrupole magnets that must be met if such errors are not to dominate the unavoidable aberrations. A general scheme, using linear programming, for optimizing first-order optical properties is included. This scheme is to be extended to allow the minimization of objectionable aberrations. The numerical calculation of the sixty-four coefficients describing the aberrations has been checked by verifying twenty-eight relationships among them that have been derived from theory based on the Poincaré integral invariants. (Philip F. Meads, Jr. and David L. Judd)

A project involving calculation and study of iron-free beta spectrometers has been started at the request of J. M. Hollander of Nuclear Chemistry. An existing spectrometer of this type, located in the field-free laboratory, has displayed anomalies that affect its resolution in an unexpected way. Thus far the work has consisted of preparing an IBM 7090 FORTRAN program, which calculates magnetic fields in terms of assumed currents in a set of circular conductors, and represents the results in terms of fitted polynomials. This program also obtains certain functions of this data, which appear in previous analytical work on the theory of particle orbits in magnetic fields of this character, as developed by Lee-Whiting at the Chalk River Laboratory in Canada. The primary purpose of this program is to aid in the interpretation of the performance of the existing spectrometer and to facilitate comparison with performance of an ideal instrument free from errors of construction and alignment. It is hoped that this program may also be useful in finding the optimum design of an instrument of this type. Further work, in collaboration with Hollander and his co-workers, is planned. (David L. Judd, Alper Garren, and Donald Chaffee)

A central goal of the Bevatron improvement program is the improvement of intensity. One of the important sources of increase is the optimization of all injection parameters. As an aid in this process, an analysis has been made of the influence, at injection, of inflector geometry, of rate of rise of magnetic field, of rf voltage, and of magnetic field shape (which determines the frequencies of betatron oscillations) on the intensity of the beam captured into phase-stable orbits. In these calculations account is taken of radial motion only. Vertical motion is ignored, and space-charge effects have not been included thus far. The approach adopted was motivated by those used for Nimrod at Harwell in England and for Saturne at Saclay in France, but the work was extended so as to be applicable to a wide variety of conditions in any weak-focusing accelerator. The resulting equations are too lengthy to be evaluated without use of a high-speed computer. An IBM 7090 program has been prepared which accepts as input the machine parameters and the distribution in phase space of the injected beam. It computes and prints the distributions of the accepted intensity in radial betatron phase space, in rf phase space, in phase oscillation amplitude, and in the time of injection, as well as giving the total intensity accepted into stable orbits. This program

is almost complete; it is expected to be useful in understanding the interplay of the various parameters in maximizing injection efficiency. (David L. Judd and Hermann Grunder, Mechanical Engineering)

One of the interesting reports at the UCLA Conference on Sector-Focused Cyclotrons in April 1962 was from the University of Colorado, by D. A. Lind and his associates, who had successfully accelerated negative hydrogen ions (H^-) to around 15 MeV in their cyclotron. After the conference it was determined that previous work by John R. Hiskes and by Robert V. Pyle et al. at this Laboratory supplied a basis for making reasonably reliable estimates of the maximum energy to which such ions can be accelerated in conventional cyclotrons, spiral-ridge cyclotrons, and synchrocyclotrons. This limit is set by dissociation in the electric field $\vec{v} \times \vec{B}/c$ due to motion in the magnetic field. The use of these ions in sector-focusing constant-frequency cyclotrons of several hundred MeV intended as "meson factories" would require magnetic fields lower than usual by at least a factor of three. However, this effect should not limit their use in the present generation of such machines of 30 to 80 MeV having $B_{max} < 20$ kG. The lower energy gain per turn in synchrocyclotrons leads to dissociation at somewhat lower energies. This work will appear in a special issue of Nuclear Instruments and Methods devoted to the UCLA Conference. As a result of these calculations, a preliminary design study of a low-field large-diameter meson-factory cyclotron has been started at UCLA. The advantage of using these ions is that they can be completely and easily extracted into a well-collimated beam; this extraction method is not only convenient and efficient but also avoids the severe problems of component irradiation and induced radioactivity inside such accelerators. (David L. Judd)

An article on alternating-gradient focusing was written for The Encyclopedia of Electronics (Reinhold Publishing Corp., New York, 1962). (David L. Judd)

During the period covered by this report a large amount of analytical and computational work has been devoted to a variety of problems in connection with the 88-inch cyclotron. A number of papers describing this work were presented at the International Conference on Sector-Focused Cyclotrons at UCLA in April 1962. These papers will soon appear in a special issue of Nuclear Instruments and Methods devoted to this conference; therefore this work will not be described in detail here. Among these topics are the development and use of computer programs (a) to accept highly precise magnetic field measurements from which are computed the properties of particle orbits throughout the machine, (b) to determine optimum currents in seventeen sets of pole-face connecting windings by use of linear programming, and (c) to study in detail the design and the optical properties of an adjustable two-segment electrostatic deflection system. In addition, the influence of various nonlinear effects on orbit properties in the outer region near extraction was examined by approximate analytical methods. Calculations relating to the 88-inch cyclotron are continuing; as operating experience accumulates, progress is being made toward achieving the high degree of flexibility of which this accelerator is capable. This work has been performed by a number of people working under the direction of Dr. Alper Garren, who is continuing the study of problems of this character during a 3-month stay (September-November 1962) at the Rutherford Institute at Harwell in Great Britain.

Studies have continued relating to the design of a large alternating-gradient synchrotron. During most of the period covered by this report, effort was concentrated on an energy of 300 BeV. Consideration was given to a number of topics (general parameters, linear accelerators, magnet ripple and transients, induced radioactivity, accelerating systems, and magnet design) on which progress is reported in the paragraphs below. More recently, interest has been focused on the 100-BeV range of energy. Studies have been begun on methods of achieving high intensity, on determination of the best type of injector, and on suitable beam-extraction methods at 100 BeV. Work on large AGS machines is under the direction of Lloyd Smith.

A. General Parameters

Tentative values have been established for the basic parameters of the accelerator, and the tolerances required for successful operation. In order to avoid difficulties at low magnetic fields an injection energy of at least 2 BeV has been chosen. This is attainable with a linear accelerator. Long straight sections with matching quadrupoles would be used at the experimental areas and for injection. (Lloyd Smith)

B. Linear Accelerator

Since a near-relativistic proton linac would be a new type of accelerator, there are many beam dynamic problems to be investigated before realistic design work could begin. An IBM 7090 program has been written that follows the longitudinal and transverse motion of individual particles through a succession of accelerating sections with independently specified parameters. The problem of transverse focusing was investigated and it was found that quadrupole doublets between sections would focus adequately from 200 MeV on up. The possibility of designing the separate sections for uniform phase velocity is being examined. This study is not yet complete, but longitudinal stability seems adequate even though the energy is as low as 200 MeV. (Lloyd Smith and Hartland S. Snyder)

C. Magnet Ripple and Transients

It was realized during the design period for the present synchrotrons that the distributed capacity of the magnet coils can cause large azimuthal variations in the guide field, since the system responds as a transmission line to variable power-supply voltage. This question was re-examined for larger machines and was found to be even more serious; ripple filters and reduced rate of rise at injection would probably be required. (Lloyd Smith)

D. Induced Radioactivity

A 300-BeV synchrotron should be capable of producing 10^{13} protons/pulse or more. It is obvious that radiation effects would have an important influence on design and operation. A study of the activation problem was therefore initiated. This study took the form of looking for a proper method to extrapolate residual activity measurements on the present machine and trying to identify the isotopes responsible for the long-lived components. At the present stage of this work, it appears certain that the primary beam should either be extracted for use or dumped in pre-arranged locations where special

handling and maintenance techniques are available. The general level of radiation in the tunnel appears to be borderline; further study is needed to decide whether or not conventional maintenance methods are allowable. Regarding specific isotopes, existing data are too meager to identify the worst ones positively, but it should be possible to establish this point with more experience and some specific measurements. (Robert E. Taylor)

E. Accelerating System

An injection velocity close to the velocity of light has the advantage that the required range of frequency modulation is small. The choice of accelerating system is thereby less restricted than in present proton accelerators. A study was made of the possibility of using 200-Mc quarter-wave lines, mechanically tuned, a system which would be spatially compact and highly efficient. Theoretical analysis of the tuning servo loop indicates that this system is feasible; measurements on a low-power mock-up have corroborated this result. (Wolfgang Schnell and Lloyd Smith)

F. Magnet Design

The magnet for a new accelerator would be similar to those of the present alternating-gradient synchrotrons, but probably not identical. Experience has shown, however, that the field distribution at intermediate fields is calculable to high accuracy from the geometrical arrangement, in cross section, of steel and coils. Thus it should be possible to by-pass much of the usual model work by computational procedures. A 7090 program was set up to solve the two-dimensional problem for C-type magnets by the relaxation method, including the dependence of permeability on flux density. Some cases have been run, with sufficient precision to show the sensitivity of field gradient to pole shape, but the convergence of the procedure is not yet satisfactory and modifications are still being made in the program. (Hartland S. Snyder and Lucy W. Person)

IX. MISCELLANEOUS CALCULATIONS

The study of very-high-energy nuclear interactions initiated at the beginning of last year has been continued. It is based on the relativistically invariant phase-space statistical model. The computer program for calculation of expected multiplicities and energy spectra of secondary particles has been improved and extended to include the recently discovered resonances. (Graham Campbell, Joseph Lepore, and Robert Riddell, Jr.)

Research has been continued on a perturbation expansion for the electrical polarization of a gas of neutral molecules.¹ The elementary derivation² of the perturbation results has been improved and the improved methods applied to the study of nonlinear and nonlocal effects found earlier by means of the perturbation treatment. Work was begun on the evaluation of the first corrections to the Clausius-Mossotti formula for a gas of spherical molecules, using a simple model for the molecules. (Louis T. Klauder, Jr.)

A simple theory of the photoproduction of π^0 mesons from complex nuclei has been studied, and the results compared with an experiment of Goodwin, Anderson, and Kenney.³ (Robert Traxler)

The relative rate of the radiative absorption of π^- mesons in hydrogen and deuterium, $T = R(\pi^- + d \rightarrow 2n + \gamma) / [R(\pi^- + p \rightarrow n + \gamma)]$, was calculated by means of the impulse and closure approximation. The result is 0.83 ± 0.08 . (Robert Traxler)

Certain properties of systems were studied in association with the Jason Division of The Institute for Defense Analyses. The work is described in an IDA report co-authored with R. Blankenbecler of Princeton University and H. Foley of Columbia University. (Andrew M. Sessler)

Various formulas relating to the partial-wave analysis for the reactions $\pi N \rightarrow \pi N^*$ and $\pi N \rightarrow \rho N$ have been derived and tabulated for use in experimental analysis. Some important aspects of the analysis concerning the cause of the higher resonances of pion-nucleon scattering have been investigated. (Gyo Takeda in collaboration with Victor Perez-Mendez)

The anomaly in the 2π mass spectrum for $T = 0$ observed in $\pi N \rightarrow 2\pi N$ reactions^{4, 5} has been investigated. The interference between the two processes, pion production by a one- π exchange process and the reaction $\pi N \rightarrow \pi N^*$, was shown to give an effect similar to one observed. A quantitative analysis is in progress. (Gyo Takeda)

¹ A Kaufman and K. M. Watson, Phys. Fluids 4, 655, 931 (1961).

² A. Kaufman and K. M. Watson, J. Chem. Phys. 36, 439 (1962).

³ L. K. Goodwin, J. D. Anderson, and R. W. Kenney, Bull. Am. Phys. Soc. 13, 421 (1958).

⁴ J. Kirz, J. Schwartz, and R. Tripp, Phys. Rev. 126, 763 (1962).

⁵ B. Barish, R. Kurz, V. Perez-Mendez, and J. Solomon, Bull. Am. Phys. Soc. 7, 280 (1962).

The polarization of K^* produced by $K^+ + p \rightarrow K^* + N$ or $K^+ + p \rightarrow K^* + N^*$ has been studied. (Gyo Takeda in collaboration with Gerson Goldhaber, Sulamith Goldhaber, and William Chinowski)

The simultaneous phase-shift analysis of the world's proton-proton scattering data at energies below 400 MeV is continuing. Parameters governing the energy dependence of the individual phase shifts are the variables in a χ^2 search. Good fits are obtained, which defines allowed phase-shift bands. The work was done in collaboration with M. J. Moravcsik and H. Pierre Noyes of the Livermore Laboratory and was reported at the 1962 International Conference on High Energy Physics at CERN. A report is being prepared. (Henry P. Stapp)

X. GENERAL THEORETICAL STUDIES

The measurement of a differential scattering cross section gives only the magnitude of the scattering amplitude (or S matrix) and not its phase. This so-called "phase problem" has been much discussed, but without a satisfactory solution, particularly in connection with x-ray analysis of structures. Two attempts to solve this problem have been made. The first involves a dispersion relation to provide a relation between the real and imaginary parts of the scattering amplitude. Unfortunately, the dispersion relation leads to a finite number of different phase functions, and so does not provide a unique solution to the problem. The second method involves a new experimental technique for doing scattering experiments. In this method two scattered particles, from different sources, are made to interfere with each other in the detector. A direct measurement of the scattering amplitude is obtained in this way. The work was done in collaboration with H. W. Lewis of the University of Wisconsin and M. L. Goldberger of Princeton University. (Kenneth M. Watson)

Recent developments in the study of analytic properties of wave functions permit an extension and generalization of the work of Watson regarding final-state interaction. A formalism is being developed for multiple final-state interactions. This includes techniques for treating inelastic processes. A study of the influence of the number of final-state particles on the observable effects of final-state interactions is included. (John Gillespie)

The electromagnetic field may be introduced into quantum theory by demanding that the gauge transformations on the Schrödinger wave functions be coordinate-dependent. The Yang-Mills field may be similarly motivated. It has been shown that the gravitational field is of the same gauge character. Parallel transport can be presented by means of a Feynman path integral, and the curvature tensor emerges from closing its circuit. The approach is essentially global rather than local as in differential geometry. (Maurice Neuman)

Two methods are employed in formulating classical statistical mechanics. The first, due to Gibbs, starts with microcanonical distributions; from it one derives microcanonical distributions which are employed in calculating averages of dynamical variables. The second, due to Fowler, starts with the averages. This latter approach has been mostly used in quantum theory. It has been shown that the method of Gibbs involving actual distributions can be carried through in quantum theory. Probability distributions underlying the Fermi and Bose means of the numbers of particles in a given state and many more general results can be obtained by this formation. With a probability distribution on hand one can easily calculate fluctuations from these means. (Maurice Neuman)

Wigner has shown that there exists a representation of the Lorentz group describing massless particles having continuous spin. The spin is described by an internal vector coordinate having two degrees of freedom. The wave function describing the free particle has infinite extent in certain directions and allows the addition of a class of arbitrary functions which equally well describe the particle. It was suggested that this corresponds to a gauge freedom and that only certain derivatives of the wave function,

which are free of ambiguity, can have physical significance. One can take advantage of this gauge invariance to postulate a "minimal" universal coupling for these particles to arbitrary fields and thus to develop a theory of interacting continuous-spin particles. (Daniel Greenberger)

Criteria have been established to test whether invariance under a continuous transformation leads to a conservation law. The scale transformation was examined as a special case, and was shown to lead to no conservation law, and to be in fact of a rather trivial nature. This is due to the artificial way in which scale invariance is usually introduced. A theory was then constructed by introducing an internal coordinate of dimension "length" in order to allow only the dimensionless ratio of lengths to appear, and by exploiting the gauge-like structure of the scale transformation. In this theory the scale transformation does lead to a new conserved current (as well as to an almost conserved one). The internal coordinate was shown to play the same role for the scale transformation as the internal coordinate spin plays for rotations. (Daniel Greenberger)

The most general linear motions that lead to a loss of information about physical systems have been investigated. Special attention was paid to those motions which preserve the uniform ensemble. They were shown never to lead to an increase in information about the systems. For quantum mechanical systems that can be described on finite-dimensional Hilbert spaces, the set of all time-development transformations of this subclass of motions forms a closed, bounded, convex set. It was shown that the extreme points of this set include transformations which are neither unitary nor anti-unitary. Studies were made of those motions in this class which can be interpreted as corresponding to a diffusion on the group manifold of a finite-dimensional Lie group. For such motions the close analogy between the description in quantum mechanics and the description in classical mechanics was stressed. The work was guided by Professor E. H. Wichmann. Some of the results have been reported.¹ (C. H. Woo)

An investigation into the mathematical foundations of phase-shift analysis has been begun under the supervision of Dr. Eyvind H. Wichmann. (James H. Crichton)

A wave equation for free particles and for a particle in a potential has been constructed which eliminates the necessity for subsidiary conditions. It is a partial differential equation of order $2s$, where s is the spin of the particle. It has not been established that this equation leads to a renormalizable field theory for higher spins, or even that it can be consistently quantized. A practical value of the equation at present might be the construction of invariant scattering amplitudes in a manner analogous to the Dirac, as opposed to the manner used in two-component spinor formalism. (David N. Williams)

¹C. H. Woo, Linear Stochastic Motions of Physical Systems, UCRL-10431, August 1962.

MATHEMATICS AND COMPUTING SERVICES GROUP

Kent Curtis

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

I. Physics

A. Hydrogen Bubble Chamber Data Analysis

Programming and allied services performed for the Alvarez Physics Group from November 1961 through October 1962 were as described below.

PANAL

Experience with PANAL¹ has shown that we should not include calculations that transform or destroy the basic Franckenstein data at such an early stage in processing. We have now transplanted such sections from PANAL to PACKAGE: namely; MATCH, the track view associations; CHOZ, choice of the best stereo pair; and CHOP, discarding end sections of tracks on the basis of stereo considerations.

The measuring projectors that produced data on punched paper tape have been modified to produce magnetic tape. Several measuring machines can record on the same magnetic tape. The data format of the magnetic tape is similar to that of the paper tape with the addition of an identification word as the first word of each record. The identification word contains a number designating measuring projector. A new section has been written for PANAL to unscramble such a tape into a format acceptable for subsequent PANAL operations.

One of the Alvarez Group's 15-inch measuring projectors, MPIA, was converted for use in digitizing film from the 72-inch bubble chamber. This projector has an IBM 026 card punch attached, and produces data on punched cards. New data formats were laid out, and an input subroutine was written for PANAL.

The layout and necessary alterations for the operation of PANAL on a two-channel eight-tape unit machine were completed. This version of PANAL will be used on the IBM 7090 at the University of California at Berkeley as well as at the other installations involved in cooperative experiments.

PACKAGE

The present version of PACKAGE² (PACKAGE II) has been modified to include the MATCH, CHOZ, and CHOP subroutines from the PANAL program. A clock routine was added to provide data on running time.

¹Physics Division Semiannual Report, UCRL-10349, May 1962, p. 37.

A subroutine for checking program and machine operation was also introduced. This subroutine uses a standard event, which accompanies the program tape, and performs the following sequence of calculations. The PACKAGE program is initialized by making use of data contained in the tape label which is the first file of every data-input tape. The checking subroutine then processes the standard event and calculates check sums on the PACKAGE results. These check sums are stored and normal data processing is begun. Once every 100 events, the standard event is reprocessed and the check sums are compared with those calculated at the beginning of the run. Deviations are noted both on line and on an off-line printer tape.

A new assembly, PACKAGE III, is being prepared in order to collect the several experiment program tapes onto one. The PACKAGE II program tapes differ only in the experiment-dependent event types and optical and magnetic-field parameters. The PACKAGE III tape will consist of the basic PACKAGE program, followed by a file for each experiment containing the experiment-dependent parameters. This system will not only centralize the PACKAGE program and permit more simple modification, but it will also aid the operation of PACKAGE on the computer.

Work has begun on a new three-view stereo-reconstruction program. The purpose of this program is to obtain more accurate data from bubble chamber film than can be achieved with the present geometry program in PACKAGE. This new method will also permit processing complete data on highly curved tracks. The track ends are now being cut off by the CHOP subroutine in PACKAGE.

A master program tape has been developed which contains the main programs used in the Alvarez Group data-processing system. This tape contains PANAL, PACKAGE III, SELECT, EPC, and LINGO. Any program may be called from this master tape by a CALL CARD.

Several "event-type" subroutines, necessary for control of the logical flow of event processing through PACKAGE, have been written for the K-72 experiment and for the associated-production experiment.

The PANAL and PACKAGE programs were revised and taken out of the SHARE Operating System (SOS). The revisions involved changing the programming language from SOS to 9AP and incorporating a new set of input-output subroutines. This change was prompted by inadequacies of the SOS system and the announcement that IBM Applied Programming Division was abandoning the system. These revised versions are capable of analyzing data at a rate of four to five events per second for PANAL, and ten events per minute for PACKAGE on the IBM 7090.

LINGO

A few more operations have been added to Library Control (a subsection of LINGO³), and improvements have been made to the previously written operations. Lists have been reworked to permit more flexible and complete listings. The operations added include measurement error tally, input tape for EDIT PACKAGE, a basic form of MODIFY.

The TALLY operation is used to produce tallies on selected items not available in the standard tallies (for example, a list, by error type, of the number of events that failed PANAL owing to Franckenstein operator error, for each operator). The EDIT PACKAGE input tape operation compares a PACKAGE input tape with the master list, selecting and writing events on a new tape according to a set of conditions (for example, select all events of type 40). The MODIFY processor is used to make corrections and modifications to the master list. This includes replacing incorrect scanning information.

A final operational assembly was prepared and is now being used in production processing in experiments on K^- and π^- in hydrogen and π^- in deuterium, all at 1 to 2 BeV. This assembly includes all basic operations required to handle event-library processing. Time accounting, using the channel D clock on the 7090, has been incorporated.

A special revision of the LINGO RESULTS operation was written for the π^2 experiment to permit replacement of previous results on the master list tape by simply updating this tape with new EXAMIN results.

A subroutine was written for the purpose of decoding the π^2 Hollerith scan cards.

Basic work has been completed on a routine, "CONFLICT," for comparing the results of two separate scans of film for one experiment. The first pass of CONFLICT prepares the conflict listing. The conflicts are resolved by the scanner, and control cards are punched. In the second pass these control cards are used to update the master list for those events listed as conflicts.

Complete instructions for the use and operation of LINGO I have been written.⁴ These notes include the information necessary for proper program setup and all details needed in order to write a LINGO I program.

Some subroutines in the LINGO system are useful to other programming efforts. To facilitate the distribution of symbolic decks and listings of requested subroutines, a program called "SYMBIOSIS" was written. SYMBIOSIS uses the 9AP printer tape along with request control cards as inputs, and produces the desired symbolic decks or listings or both.

³Physics Division Semiannual Report, UCRL-10349, May 1962, p. 39; UCRL-9704, May 1961, p. 30.

The LINGO input-output subroutines were modified to include symbolic tape assignment. During this period, production delays and operational difficulties encountered by the library personnel have required a considerable amount of consulting and supervision to smooth out the total library operation.

SUMX

SUMX⁵ is designed to aid the physicist in surveying the data resulting from a large number of events processed event by event with the programs PANAL, PACKAGE, and EXAMIN. SUMX can be made to do many things, but it was originally conceived to do simple tasks such as making a histogram on the basis of one word from each event on an EXAMIN output tape, or a scatter plot based on two words of data.

Because summary tapes from EXAMIN are apt to contain more than one type of event, certain selection routines have been built into SUMX. This selection has been made quite general in the hope that it would serve the purposes of most physicists.

The read section is separate to allow for different forms of EXAMIN output. One standard read routine is supplied, and if a user's format does not conform to the conventions of this routine, it can be easily replaced. There are two such alternative read routines at present, namely, CARDEX and READX.

An executive routine for tape handling is included. The input-output subroutines have been written to permit the use of SUMX at other installations such as UCLA, Florida State, CERN, etc. where configurations of the computing machines are different from those at Berkeley.

The organization of SUMX for making histograms or other simple lists is quite general. The main program merely calls subroutines--designated SELECT, TAPE, and BLOC 3 to BLOC 15--on the command of data cards which follow the binary SUMX deck. SUMX has no control over what the user chooses to put in these BLOC subroutines. Several "standard" subroutines (BLOC's) are provided to do simple things, as follows.

- BLOC 3 Make a simple histogram of up to 200 bins.
- BLOC 4 Construct Gaussian, Idea-gram and Resolution functions.
- BLOC 5 Make up to five pictorial histograms per pass for up to 110 bins.
- BLOC 6 Make up to five two-dimensional histograms per pass for up to 15×20 bins.

⁴Samuel Penny, LINGO Systems Memo, Alvarez Programming Note P-7, Jan. 4, 1962; Operating Instructions for LINGO I, Alvarez Programming Note P-8, Sept. 11, 1962.

⁵Lynn Champomier, SUMX, Alvarez Physics Note No. 389, June 21, 1962.

- BLOC 7 Make one GRT scatter diagram per pass. Can make a Dalitz plot.
- BLOC 8 Make lists of eleven words per record plus event identification.
- BLOC 9 Make ordered list of one word per pass.
- BLOC 10 Make up to ten simple histograms per pass for up to 110 bins.

The use of the subroutine that makes graphs and histograms on the cathode-ray tube permits one to make several displays on a single pass of an input data tape.

SUMX is now being used extensively in experiments by the Alvarez Physics group (e. g., K72, π 72, APE).

EXAMIN

Several experiment-dependent EXAMIN⁶ subroutines were written and used during this period. They include:

EXAMIN 24: A series of calculations used in connection with the analysis of the omega resonance;

Subroutines for the calculation of production and decay angles (in the laboratory reference system) for the deuterium experiment designated 0.5; and

A buffered read subroutine, "READ K72," written for the EXAMIN system and first used in the analysis of the K72 experiment. This routine permits faster reading of the long, complicated PACKAGE output tapes.

WRING and EXAMW

Together the two new programs WRING and EXAMW⁷ serve to extend the power and flexibility of the EXAMIN System (EXAMIN is described in Alvarez Physics Memo 271). The WRING program compacts the data written on binary tape by PACKAGE, and rewrites these data in an abbreviated form. For example, the large GUTS error matrix is normalized and triangularized. EXAMW reads this abbreviated format and performs the operations currently done by EXAMIN. Programs are available to order and merge data from several WRING output-format tapes, and the K72 library system is being modified to provide the facility for matching events from WRING tapes with events from a master list. This system parallels the present EXAMIN system and will eventually supersede it.

⁶Dave Johnson, The EXAMIN System, Alvarez Physics Note No. 271, March 16, 1961.

⁷Dave Johnson, WRING and EXAMW, Alvarez Programming Note P-5, August 31, 1962.

FILTER

At the end of March 1962, FILTER⁸ had processed several events measured on the Spiral Reader; however, the percentage of events successfully handled was small. Several modifications are being tried in order to speed up the development of both FILTER and the Spiral Reader. One x, y measurement on each track has been added, and FILTER has been modified to handle these new data; in addition, the method used by FILTER to process Spiral Reader measurements has been improved. Extensive tests are being made on a large sample of data. Effort is being made to obviate x, y measurements on each track, since this is a time-consuming process.

Calibration and distortion routines FRIGID, CALIB, and DISCON have been written for the Spiral Reader. The routine FRIGID reads a Spiral Reader tape and test each bit to determine deviations from the expected statistical occurrence. The program CALIB is divided into two sections. The first section, straight-line calibration, measures the orientation of the polar coordinate system with respect to the Cartesian coordinate system on the Spiral Reader. It also measures any angle-dependent radial distortions that may be present. The second section, circular-arc calibration, determines the magnification of the Spiral Reader optical system. It calculates radial distortions and attempts to fit them to a cubic function of the radius. The routine DISCON determines if there is a discontinuity or bend in the measurement of a straight line; this program is used to detect misalignment of mirrors in the Spiral Reader.

SMP

A 709 program, CHIT-CHAT, was written so that one can do film scanning with the SMP (scanning and measuring projector)^{9, 10} on line to the computer. CHIT-CHAT was designed to permit time sharing of the 709 with another program subject to certain restrictions on the size, etc., of the second program. An IBM typewriter connected to the 709 through the direct data lines is used for input and output communication between the scanner and the computer.

Programs were written to display SMP measurements on the CRT and to fit measurements of a straight line for calibration studies.

The SMP executive routine that controls the input of coordinates and the input-output from the typewriters using the direct-data interrupt has been designed and coded and is being debugged. This system was designed to control the operation of three SMP's on line to the IBM 709, including

⁸Daphne Innes, FILTER, A Topological Pattern-Separation Computer Program, UCRL-9461, November 1960.

⁹Luis W. Alvarez et al., SMP-1 Scanning and Measuring Projector, UCRL-10109, April 1962.

¹⁰J. N. Snyder, Some Remarks on a Data Analysis System Based Upon the Scanning Measuring Projector (SMP), Alvarez Physics Notes No. 326, August 25, 1961.

recording, measuring, checking, filtering, and editing data in the correct format for subsequent PACKAGE processing. The prototype SMP is the only machine available at present, so that it is not yet possible to check the logic with multiple SMP's. Recent modifications to EXEC include the ability to switch from one script to another (a script is a series of calling sequences for processing routines). Previous plans called for completely different scripts to perform even slightly different tasks.

Two programs have been written which together will follow a track with varying degrees of success. These programs are called "INITIAL" and "SLEW." INITIAL examines points from the first 2 cm of measurement and attempts to determine the direction of the track (or tracks). The output from INITIAL may actually include several tentative tracks, each defined by a point and a slope, and presented in decreasing order of probability of being a true track.

"SLEW" examines the remaining data points and attempts to fit them in with the tentative tracks from INITIAL. The acceptance criterion used is based on the deviation of a new point from the previous projected line. Several ideas for improving this method are being studied.

Procedures are now being designed to use the SMP as simply a measuring device for prescanned film. This will involve some new logic for the control of measuring, or scanning, or measuring and scanning. Areas still to be completed include (a) the analysis of methods to handle detectable errors resulting from the SMP optical corrections, and (b) equipment for television display.

QUEST

An octal-decimal dump operation has been added to the QUEST program¹¹⁻¹³ to facilitate on-line debugging from the QUEST typewriter. A report subroutine has also been added to give the user additional KICK information on fitted track data. The general raw-data print routine, EPC, has been added to the QUEST program tape to allow automatic processing of a QUEST binary output tape following a run. The QUEST program has been in operation for the K72 experiment; however, the program is currently being extended to handle other experiments. This revision will be made first for the APE (associated-production experiment) and the π^2 (π^- in hydrogen) experiment. Necessary alterations include a provision for loading optical constants and other experiment-dependent parameters at running time on commands from the QUEST typewriter.

¹¹L. Stevenson, The Interrogation System, QUEST, Alvarez Physics Note No. 342, Oct. 18, 1961.

¹²M. Alston, Q*, On-Line Event Type Writing Program, Alvarez Physics Note 386, April 11, 1961.

¹³Margaret H. Alston, James E. Braley, and Peter White, QUEST--An On-Line Event-Processing Routine (UCRL-10400, Oct. 1962), submitted to Rev. Sci. Instr.

Another QUEST development in progress involves attaching a measuring projector on line to the IBM 709. This will permit the measuring of events and the immediate processing of the measurements through use of the QUEST program. What may turn out to be even more important is that if an event should fail the analysis because of poor track measurement, the operator may remeasure only the offending track and subject the event to reprocessing without the usual long time delays.

PHASE SPACE

The PHASE SPACE programs¹⁴⁻¹⁹ reported earlier²⁰ were subjected to numerous production runs. Minor modifications were made and extensive checking has been performed both through hand calculation of partial results and through cross-checking by using several independent methods to calculate the same quantities. The program write-ups have been completed.

MINFUN

An off-line graph routine "DISPLA" was added to MINFUN.²¹ This graph can plot the progress of the minimizing search for fast analysis by the user. Another subroutine, "KEY," was added to allow on-line control of the step size used in the ravine method.

Miscellaneous

Modifications were made to existing programs for the LEPTONIC experiment. The library routines^{20, 22} for data from the 15-inch chamber were revised for experiment 12. These changes included format differences and input-output modifications required because these programs were written for the IBM 704.

¹⁴ Mark Horovitz, A Summary of Available Programs for Calculating Phase Space Distributions, PHASE SPACE Distributions, Alvarez Physics Note No. 392, May 23, 1962.

¹⁵ M. Horovitz, BEIDEN, Alvarez Physics No. 393, May 1962.

¹⁶ M. Horovitz, ATHOS, Alvarez Physics Note No. 394, May 29, 1962.

¹⁷ M. Horovitz, 4-Body Phase-Space Program H4, Alvarez Physics Note No. 395, May 23, 1962.

¹⁸ M. Horovitz, 5-Body Space Program H5, Alvarez Physics Note No. 396, May 23, 1962.

¹⁹ M. Horovitz, 6-Body Space Program H6, Alvarez Physics Note No. 397, May 28, 1962.

²⁰ Physics Division Semiannual Report, UCRL-9704, May 1961, p. 33

²¹ W. E. Humphrey, A General Minimizing Routine—MINFUN, Alvarez Programmer's Note P-6, September 7, 1962.

²² Ron Ross, Elastic Scattering of K^- Mesons in Hydrogen (Thesis), UCRL-9749, June 21, 1961.

A subroutine FCN was written to calculate the value of any function and its derivatives. In its present form, FCN can call up to ten different subroutines describing functions.

Personnel

The work described up to this point was done by Robert Harvey, Benjamin Abington, Silverio Almeida, Lynn Champomier, Barbara Cottrell, Cecil Draper, Bill Graziano, Joe Hanna, Mark Horovitz, Marjorie Hutchinson, Daphne Innes, David Johnson, Ralph Jones, Max Leavitt, Alice McMullen, Jack Merkin, Barrie Pardoe, Sam Penny, Tom Schneider, Jon Stedman, Tom Tonisson, Linda Watkins, and Hovan Zarian.

FAKE and GENPCM

A 7090 program, FAKE, which simulates particle interactions in bubble chambers, was completed. This program permits the simulation of up to four connected events, each involving up to seven particles, and yields kinematic data corresponding to measured quantities for such events. It is expected that this program will be used to study sources of error and bias in the analysis of bubble chamber experiments. A 7090 Monte Carlo program, GENPCM, was written to generate and randomly orient momenta corresponding to particle interactions involving up to eleven particles. GENPCM is used in phase-space calculations and in obtaining effective-mass distributions. The program is expected to be of use in analyzing experimental data for particle resonances. (Grove Nooney for the Alvarez Group)

The Expediting System

In an effort to secure maximum efficiency in the processing of Alvarez Group computing jobs, an expediting system has been established. The present system is the latest in a sequence of approximations, each of which was necessitated by an over-all increase in data-processing activities.

The system is staffed by a full-time expeditor, five part-time expeditors, and four key-punch operators.

The services provided include:

Constant surveillance of the group's machine time, usage, and needs.

Complete keypunch service.

Maintenance of various records which serve as main sources of information regarding machine time and key-punch usage.

Maintenance of the group's tape-storage areas.

Complete computer job service, including job setup, delivery, and return from the computer.

(C. Toland Draper and Robert Harvey for the Alvarez Group).

B. Additional Bubble Chamber Analysis

Two Monte Carlo programs, KMUTHY and KNETHY, have been written for the 709.

KMUTHY calculates the complete decay configuration of a K^+ meson decaying into π^0 , μ , and ν particles. The energies, direction cosines, and potential paths of the three secondaries and of the two γ rays resulting from π^0 decay are calculated from the probability densities supplied by the theory. The energy distributions and certain angular distributions of these particles are also calculated.

KNETHY calculates the complete decay configuration of a K^0 meson decaying into π^\pm , e^\pm , and ν particles. In addition to calculating the energies, direction cosines, and potential paths of the secondaries, this program also calculates the electron-detection probability, and range-energy histograms. (Carl Quong for John Brown)

A least-squares program has been written for finding the degree and coefficients of a polynomial that would best fit some given γ -ray data (mean free paths versus energy). (Carl Quong for John Brown)

A program was written to make a maximum-likelihood estimation of a parameter in the $K_{\mu 3} - \pi^0$ momentum spectrum. (Bill Benson for John Brown)

A maximum-likelihood program to obtain the best fit to the pion energy spectra in $K^+ \rightarrow \pi^+\pi^+\pi^-$ and $K^+ \rightarrow \pi^+\pi^0\pi^0$ decay was written. Results from this calculation can be used in tests of validity of the $|\Delta\vec{T}| = \frac{1}{2}$ rule in non-leptonic decays. (Bill Benson for John Brown)

A bubble chamber design program was written to determine a satisfactory distribution of lights illuminating a bubble chamber. The program calculates, for various points on a film, the intensity of light scattered from bubbles in the chamber. (Bill Benson for John Brown)

A CERN multivertex fitting program is being adapted specifically for analysis of $K^+ \rightarrow \pi^+ + \pi^0 + \pi^0$ decays observed in a xenon bubble chamber. The fitting of kinematic variables at all vertices simultaneously should remove many of the difficulties encountered in the present (TAUFOR) analysis program. (Bill Benson for John Kadyk)

To aid in the design of a possible Bevatron experiment, we wrote a program to determine to what extent $K^+ \rightarrow e^+ + \pi^0 + \gamma$ events (K_{e3}^+) (events in which only one of the γ 's from the π^0 decay is detected) simulate the rare decay mode $K^+ \rightarrow e^+ + \gamma + \nu$. The program tests K_{e3}^+ events generated by the Monte Carlo program KETHY²³ to see what fraction of them satisfy, within the assumed measurement errors, the tests appropriate to the $K^+ \rightarrow e^+ \gamma + \nu$ mode. (Bill Benson for John Brown)

As an aid to interpretation of the results of a xenon bubble chamber experiment on the $K^+ \rightarrow \mu^+ + \pi^0 + \nu$ ($K_{\mu 3}^+$) decay mode, a program was written to calculate various energy and momentum spectra and angular correlations. The program allows theoretical parameters to be changed, and incorporates necessary experimental corrections to the data. The program output enables us to see clearly how the conclusions drawn in the experiment depend on the data, and allows us to isolate the effects of conceivable experimental biases. (Bill Benson for George Trilling)

²³KETHY was previously described in Physics Division Semiannual Report, UCRL-10349, May 1962, p. 46.

A number of FORTRAN codes, based on the EXAMIN system, were written during this period for selecting specific data from KICK output tapes and performing various testing and further computing operations. Various angular distributions, masses of combinations of particles, and variances were obtained for events in both the low-energy K^+ experiments with the 15-inch bubble chamber and the recent 2-BeV experiment done at Brookhaven. Also, several programs were written to perform sorting operations on these results.

A program that combines the distribution of the lengths of leaving tracks in the fiducial volume and the distribution of their energies in the 15-inch bubble chamber was also written.

A program was written that, using all available K^+ and K^- scattering data, computes certain integrals and coupling constants occurring in the dispersion theory of strong interactions; it also computes the combined errors due to all the parameters involved. (Fred Andrews for Sulamith Goldhaber and Gerson Goldhaber)

Work has been done to adapt the PANG, KICK, PANAL, and PACKAGE programs (Alvarez, Bubble Chamber) for use in processing data from the Brookhaven 20-inch bubble chamber. These programs have been changed as follows:

1. Optical Constants

Fiducial positions, camera positions, chamber position, etc., have been inserted into the 15-inch processing routines of PANG. A usable set of these optical constants is now available and further refinement in the near future is contemplated.

2. Data Conversion

Events in the 20-inch bubble chamber are photographed on four films, whereas events in the 15-inch chamber are recorded on only two films. This necessitates a modification in Franckenstein handling for the film from the 20-inch chamber. The data-conversion routine merges the two input tapes obtained from the 20-inch Franckenstein, sets the correct camera relations between the chambers, inserts missing fiducials, control characters, etc., and outputs data in the 15-inch format for processing by PANG.

The data-conversion routine is now contained as a separate portion of the PANAL program tape for use on the 7090. Future modifications of this routine will include making it an integral part of the PANAL program used for 20-inch data.

3. Magnetic Field

A simple equation to calculate the Z component only of the 20-inch chamber's magnetic field has replaced the 15-inch field routine of PANG. Work is in progress to adapt the 72-inch field routine of PACKAGE for 20-inch use. Future considerations include a table lookup for field values.

4. Processing

The details of 20-inch bubble chamber processing discussed in paragraphs 1, 2, and 3 above have been incorporated into the latest versions of PANAL and PACKAGE available from the Alvarez Group. (Kirmach Natani for Sulamith Goldhaber, Gerson Goldhaber, and William Chinowsky)

C. Segrè Group

Two previously written programs were modified and one new program was written, as follows.

A 7090 program that analyzes data from a cyclotron experiment measuring $\pi \rightarrow e + \nu + \gamma$ has been modified. The original program tabulated the counter statistics, which were then recorded directly on magnetic tape. The present program has been modified to tabulate almost all possible counter correlations, and the output format has been changed. (Joe Good for Robert Bacastow)

A 7090 program that calculates fits to data from a π - π scattering-length experiment has been modified. The original program fitted data to phase-space calculations (with resonance factors added), after folding in experimental resolution. Modification consisted of a generalization of the program to automatically vary the input so that we could observe the sensitivity of the results. (Joe Good for Norman Booth)

A 7090 program was written to calculate p-p cross section and polarization parameters from phase shifts following the method of Chew-Ball-Fulco. (Joe Good for Herbert Steiner)

A 7090 program was completed to perform phase-space calculations for the reaction $\pi \rightarrow e + \nu + \gamma$. The program makes use of the simplifications for zero-mass particles and is not valid for a general decay. (Joe Good for Rudy Larson)

A 7090 program was completed to provide double-buffered binary tape input-output. This program is not intended for general use. (Joe Good for Joe Lach)

A 1401 program, CARAT, was completed to combine binary tapes. This program is not intended for general use. (Joe Good for Joe Lach)

D. Accelerator Design

IBM 7090 codes were written to perform computations based on measured data from the 88-inch cyclotron, to obtain optimal trim-coil currents, and predict fields for these currents. Other codes are being revised for the purpose of improving the process. A summary report on the system of computer codes used²⁴ was presented at the International Conference on Sector-Focused Cyclotrons at UCLA. A more detailed report is being prepared.²⁵

²⁴A. Garren, J. Young, and A. Kenney, Computational Procedure in the Adjustment of a Cyclotron Magnetic Field by Trim Coils, UCRL-10075, March 2, 1962.

A series of computations was performed to obtain optimal trim-coil settings for α particles at low- and high-energy fields and for protons in the middle-energy field. The adjusted predicted fields, phase shifts, and gradient fluctuations were calculated and the fields were processed for deflection studies. (Ardith Kenney for Alper Garren)

Additional computations were performed for the Magnet Test Group's reports for the cyclotron conference. (Ardith Kenney and Jonathan Young for Alper Garren)

The isochronization code, DORO, and the cyclotron equilibrium orbit code, ORO, were rewritten for the 7090 and combined to form a more efficient operating procedure. ORO has been incorporated into a new code that generates equilibrium orbit tables for use with the other orbit programs. (Herman Owens and Ardith Kenney for Alper Garren)

The general orbit code, GOC, was used to study the effect of a harmonic bump in an attempt to coordinate this effect with the electrostatic extraction method. Indications are that such a bump, properly placed, may be helpful. (Herman Owens for Alper Garren)

We made deflection studies for 65-MeV α particles, 50-MeV protons, and 65-MeV deuterons, using the 704 deflector program, CYBOUT. 25 A new deflector septum, which was a compromise between two previous septums, was designed and built for the 65-MeV α particles. Feasibility studies are now under way to determine its usefulness with 50-MeV protons and 65-MeV deuterons. (Herman Owens for Alper Garren)

The 7090 versions of CYBOUT and GOC are nearly complete.

A FAP program is being written which will describe the median-plane field of an array of concentric iron-free solenoids. The coefficients of a power-series expansion of the field will be used to evaluate significant perturbations up to sixth order in the focusing of an iron-free $\sqrt{2} \pi$ beta spectrometer. (Donald Chaffee for Alper Garren)

A 709 program, SYNCH 2, has been written and debugged. This program determines the acceptance of particles in a weak-focusing synchrotron. The output is:

The totally accepted beam.

The accepted beam for a given location in the α, x phase space (where α = initial angle upon entering a vacuum chamber and x = initial radial coordinate).

The accepted beam for a given location in the energy-spread phase space.

The accepted beam as a function of injection time.

The accepted beam as a function of rf phase.

(Barbara Steinberg for Herman Grunder)

²⁵ Described in Physics Division Semiannual Report, UCRL-10349, May 1962, p. 45.

Two programs, SQELCH and SURVEY, were written and are currently being run on production. These programs error-check and correct field measurements from the 88-inch cyclotron. A major modification in SURVEY has been made so that all Magnet Test Group data can be error-checked and simultaneously compared with other data when desired. Both versions of SURVEY are being used independently.

A program was written to make a harmonic analysis of field measurements from the 88-inch cyclotron. In addition, this program plots the harmonic components on the CRT as output.

Work has been begun on the 7090 programs that will be used in processing and error checking magnetic-field measurements of the Bevatron's auxiliary magnets by the Magnet Test Group.

The 7090 FORTRAN programs HAMEFIT and SURVEY were modified so that magnetic-field measurements, to be taken for testing the full-scale magnet for the 72-inch cyclotron at Davis, could be processed and error-checked at the Campus Computer Center. In preparation for full-scale magnet testing, these modified versions were used for processing and error-checking magnetic-field measurements taken on a scale model of the 72-inch cyclotron magnet. (Bert Albrecht for the Magnet Test Group)

We have assisted the Cyclotron Group from the Davis Campus in using the codes written for 88-inch cyclotron work. Some codes have been revised for use on the 7090 at the Campus Computer Center. (Ardith Kenney for Alper Garren)

A feasibility study was made to determine the usefulness of an electrostatic deflector in deflecting 100-MeV protons in the Davis 72-inch cyclotron. (This work was done in cooperation with Mr. T. McCarthy of the Davis Campus.)

A FORTRAN program using measurements in units of effective quadrupole length²⁶ was written for the IBM 7090 in order to calculate the parameters of quadrupole field strength for various values of object and image distances. (Claudette Ruge for Claude Ellsworth)

A FORTRAN program was written to provide a least-squares fourth-order polynomial fit of magnetic-field data. (Donald Chaffee for Alan Grebene)

E. Crowe Group

Several programs have been written to help in the analysis of an experiment involving the decay products of K^+ particles.

A FORTRAN program, BBQ IDEAL, was written for the IBM 7090 to analyze the behavior of various particles in a spectrometer. By spectrometer we mean an arbitrary sequence of quadrupoles (convergent in either the horizontal or vertical plane) and counter planes, followed by a deflection magnet with circular pole pieces (which also contains counter planes),

²⁶Harold A. Enge, Ion-Focusing Properties of a Quadrupole Lens Pair, Rev. Sci. Inst. 30, 248 (1959).

followed by a final bank of counter planes. Allowance is made for input of an arbitrary aperture sequence--that is, a sequence of rectangular apertures in the counter planes through which particles are expected to pass. For a fixed monoenergetic point source, P, a given aperture sequence induces, on the unit sphere centered at P, a region R in which those particles passing through all the apertures intersect the unit sphere about P. The calculations made included:

1. for a given radial angle about the axis, the widest possible deflections from the axis with which a particle will pass through all the apertures ;
2. the solid angle of R, that is,

$$\int_R dA/4\pi; \text{ and}$$

3. the average distance, that is,

$$\int_R s dA / \int_R da,$$

where dA is an element of surface area and s is the distance traveled by a particle passing through dA .

Tracking of particles is done, for the quadrupole region, by means of optical approximations, and for the deflection-magnet region, by circular arcs in the plane parallel to the pole faces. Linear tracking is used in the intervening areas of low field strength, with an approximate correction for fringe fields around the deflection magnet.

Optional corrections are made for momentum loss in passing through the counter planes; these corrections may vary in amount with the type of particle. Optional allowance is also made for scattering at the counter planes to facilitate study of the effect of scattering on the integrals.

A FORTRAN program, BBQ EXACT, was started for the IBM 7090, continuing the analysis of particle behavior in spectrometers of the type analyzed by BBQ IDEAL. The purpose is to provide for actual tracking of particles a 30,000-point table of field strengths throughout the spectrometer area. The differential equations of motion in a varying magnetic field will be solved in regions of rapid variation if necessary to obtain adequate accuracy. Maxwell's equations will have to be solved in the area of the deflection magnet to complete the table of field strengths, as readings were taken only normal to the pole faces. (Leslie Wilson for Hans Kruger)

An IBM 709/7090 FORTRAN/FAP program, CODE, which prepares data for input to a sorting program, was completed. Several tests were added to detect errors in the data cards. Also, output is now written onto a BCD tape. (James Eusebio for Hans Kruger and Bob Beck)

A FORTRAN program, RANGE, for the 709/7090 was written to compute (approximately) the depth to which a given particle (for example, π^+ , μ^+ , e^+) will penetrate a block of a given material (for example, Al, Cu, etc.). More exactly, the differential equation describing the loss of momentum of the particle is integrated step by step until either the momentum or the momentum loss becomes sufficiently small.

A least-squares FORTRAN program, UNMUON, was modified for the 709/7090 computers. UNMUON was designed to fit the input data to an unpolarized muon spectrum. The modified program, KAON, carries out the same fitting procedure, but the theoretical spectrum (fit function) is now to be supplied by the user as a subroutine. (James Eusebio for Bob Beck)

A 709/7090 FORTRAN/FAP program, SELECT, was written to select or reject sorted data (see CODE, above) according to criteria concerning certain combinations of counters or counter planes or both. This program is now being expanded to assign momentum values by a table lookup, and to identify particles.

A FORTRAN program for the 709/7090 was written to compute the momentum loss of a particle traveling through a series of materials. Given the final momentum of the particle, we integrate a differential equation backwards through the various materials to the point of generation of the particle. (James Eusebio for Hans Kruger and Bob Beck).

A system of programs written in FORTRAN and FAP for the IBM 7090 constitutes a Monte Carlo model of a shower of particles produced in heterogeneous material in a magnetic field. The output of the program will be several types of histograms showing the numbers of particles passing through an arbitrary plane as a function of energy. These will be used in connection with an experiment in which mesons hit a beryllium target and the decay products pass through a magnetic field and scatter into an array of various materials, the arbitrary planes being represented by banks of scintillation counters. (Marjory Simmons for Bob Beck)

A 650 program was written to make a least-squares fit to a curve originally having discontinuities at two points. The curve was then made continuous by interpolation at the points of discontinuity. (Edna Williams for Hans Kruger)

F. Plasma Physics

A program, MODVARMINT, has been written to provide a data-reduction scheme for use in measurements of ion density in highly ionized hydrogen gases having a density range of 10^{15} to 10^{16} protons/cm³ and having a temperature in the neighborhood of 10^4 °K. The program uses measured oscilloscope tracings as data. It fits theoretical hydrogen spectral-line profiles (whose shapes are a function of proton density) to experimentally determined spectral-line profiles. (Edna Williams for Gordon Spillman)

In the investigation of how much energy per cubic centimeter is radiated from a plasma, an IBM 7090 FORTRAN program was written that, given the measured light intensity, calculates the volume of light radiated from the plasma. (Claudette Rugge for William Cooper)

A 7090 FORTRAN program was written for the calculation of hydrogen absorption coefficients from line and continuum intensities. (Edna Williams for William Cooper)

G. Spark Chambers

A group has been formed that will investigate, implement, and sustain procedures for the collection and reduction of spark-chamber data and support the research of spark-chamber development and allied fields. This group will support the Lofgren and Moyer Groups, who are currently carrying on research in this field, and other groups that may become interested. The ultimate aim is to create a working system to satisfy present spark chamber needs, and also provide capacity for future expansion. Research and preliminary programs are in process for evaluating data from the latest experiments. These investigations are concerned with statistical evaluation of the data, errors caused from system distortions, reconstruction of data points to some spatial configuration, and orbit calculations. (Donald Zurlinden)

Work has begun on a PANG-type program in FORTRAN to handle spark chamber data. In the experimental setup, the images of several separate spark chambers have been directed (through the use of mirrors) at a single camera. Hence, the program must refer the images of the spark chambers to their correct locations in real space, magnify them to original size, and remove distortions introduced by lenses and mirrors. Information on the z coordinate of each spark will be obtained from the horizontal displacement of a reflected image of the spark. Other parts of the program will be concerned with the kinematics of the events. (Armond Nirdlinger for the Moyer Group).

A FORTRAN program was written for computing charged-particle orbits in the field of the Sagane magnet. This program is to be used by the Lofgren Group in the analysis of data obtained from spark-chamber experiments. (Victor Brady for Lofgren Group).

Numerical methods were developed to calculate charged-particle orbits through magnetic fields and for fitting convenient functions to magnetic-field measurements. (Grove Nooney for Carl Noble, Jr.)

CORETAB was written to perform interpolations on two-dimensional tables used in applying corrections for Coulomb repulsion in events of the type $\gamma + d \rightarrow \pi^- + 2p$. (Elaine Hovorka for Robert Kenney).

A 7090 program, PIFS, was written for generating a set of events of the type $\gamma + d \rightarrow \pi^- + 2p$ [i. e., $p_s + (\gamma + n) \rightarrow (\pi^- + p_w) + p_s$]; this program permits selection of initial conditions to make these events observable in a deuterium bubble chamber. The input parameters in the photon-neutron system are the total system energy and the angle between the photon and the emitted pion. For each of a series of energies (lab) of incident photons, one chooses a complete range of values of the pion momentum and of the azimuthal angle of the proton p_w about an axis defined by the pion momentum. Neglecting a trivial rotation of the entire event, these parameters are sufficient to determine the event completely. The laboratory-system momentum and laboratory angle with respect to the incident photon of all three particles (π^- , p_w , p_s), together with other kinematical data, are printed. (Elaine Hovorka for William Swanson).

H. Miscellaneous Physics Programs

Three 650 routines, RECOIL I, RECOIL IP, and RECOIL II, were revised to give differential dose calculations for nuclear emulsions exposed to neutrons in and around human phantoms. In addition, RECOIL II computes a proton track-length distribution and a special 30-point angular distribution of the proton recoils. (Edna Williams for Richard Lehman).

A FORTRAN program is being written to fit data from a gamma-ray analysis on a scintillation spectrometer. The data represent the intensity of gamma rays as a function of energy. The fit is found by least squares, and the energies are found by interpolation of normalized Compton components. (Gordon Sutherland for John Ringle).

A program was written to fit, by least squares, experimental data representing the flow rate of helium atoms through ceramic materials, as measured by a mass spectrometer. The experiment includes measurement of helium diffusion through the ceramic material, and the absorption of helium atoms by the material. (Gordon Sutherland for Perry Studt).

A FORTRAN program was written which uses the optical model to predict the scattering of high-energy nucleons by complex nuclei. The program predicts scattering amplitudes from complex optical potentials, and compares calculated values of the differential cross section, polarization, and total cross section with experimental results. (Barbara Levine for Paul McManigal).

A program was written for the 7090 Computer to solve some simultaneous nonlinear equations arising in solid-state physics. (Marjory Simmons for Georges Saada).

A 7090 program for cyclotron orbits was modified. The original program calculates the motion of a charged particle in a magnetic field $H \approx H(r)$. The modification consisted of calculating a slightly better approximation to the vertical motion. (Joe Good for Morris Pripstein)

A method to find the eigenvalues of the radial Schroedinger equation with a Yukawa potential was formulated by utilizing the Rayleigh-Ritz method. A FORTRAN program was written to compute the energy eigenvalues as a function of angular momentum and potential strength. Several eigenvalues were calculated for comparison with those computed by members of the Theoretical Physics Group, who used a numerical integration iterative method. (Paul Concus for Geoffrey Chew)

A FORTRAN program to be used for computing eigenvalues of a differential equation in one variable was completed. With this program and a potential function supplied by John Hiskes of the Livermore Laboratory, the bound state of the molecular ions He^3H^+ , He^4H^+ , He^3T^+ , He^4T^+ , He^3D^+ , and He^4D^+ were computed. (Victor Brady for John Hiskes)

Computation of equilibrium shapes of charged liquid drops was continued. (Victor Brady for Wladyslaw Swiatecki)

A FORTRAN program was written to calculate the linear distribution of D^- ions stripped by a high magnetic field. (Barbara Levine for Selig Kaplan)

A 7090 program, ARLRAP, which computes and plots the root locus of any algebraic function having up to 39th order, was written in Livermore and is described in Pluto Technical Notes Numbers 224²⁷ and 238²⁸. Modifications have been made to make it possible for the program to be run by use of the Monitor and CRT systems in Berkeley. Additional modifications are now being incorporated to change the CRT output and to allow for the method of compensation, by which additional poles and zeros may be given as input. (Barbara Steinberg for Edward Hartwig)

A FORTRAN program that numerically evaluates several complex functions arising in electronic circuit theory was completed. (Armond Nirdlinger for Larry Scott)

A program was completed which prints out the polarizing combinations for three- and four-pin keying on a 22-pin board. (Armond Nirdlinger for Ed Pullen).

A FORTRAN program was written to investigate the end correction to fourth and sixth order for a solenoid. This was done by varying the two parameters of two end-correcting coils. (Donald Chaffee for Walter Bagdad).

The existing FORTRAN program 42BB (which solves the differential equation of motion for the expansion system of a 25-inch liquid hydrogen bubble chamber), was modified. (Dave Stevens for John Myall).

An IBM 709 code, HOTAIR, was written to compute various specified complex functions of a real variable. (Jonathan Young for D. Sachs).

A series of 7090 programs to simulate a π - μ experiment is being written. The programs compute lines of foci for a bending magnet, and energy spreads seen by counters along these lines. (Thomas Clements for Julius Solomon).

The FORTRAN program, HYPERFINE 4, was completed and put into production. The purpose of the computer program is to reduce a set of atomic-beam research data by means of a least-squares fit and determine the best fit for a subset of the five parameters magnetic dipole, electric quadrupole, octupole moment, the Landé g factor, and the nuclear g factor. The experimental data are in the form of frequency for an observed resonance as a function of magnetic field for arbitrary hyperfine transitions for a given spin and angular momentum. By use of the final values of the parameters, the energy levels and residuals are calculated for each datum. (Donald Zurlinden).

²⁷ James A. Galvin, THE RAP CODE, Pluto Technical Note No. 224, April 25, 1961.

²⁸ James A. Galvin, THE ARL* CODE, Pluto Technical Note No. 238, August 28, 1961.

HYPERFINE has been converted to a 709 program. Modifications have been incorporated which primarily change the form of input-output and allow more flexibility in processing the data. The program has been completed, except for a write-up. (Barbara Steinberg for Howard Shugart).

A program has been written which calculates the energy per unit solid angle seen by a counter. Measured wire-current orbit data are converted to an energy scale that takes into consideration energy loss in the counter; the data are then numerically integrated to give energy per unit solid angle. (Carl Quong for Julius Solomon)

Work was started on a FORTRAN program to be used for computing orbits of charged secondary particles in the magnetic field of the Bevatron. (Victor Brady)

II. Chemistry

Several programs have been written for the Chemistry Group.

Work was begun on the numerical calculation of the roots and weight coefficients for a Gauss-Laguerre quadrature formula to evaluate integrals that behave like $X^{-\frac{1}{2}} e^{-X}$ times a polynomial in X . (Paul Concus for John Rasmussen)

An IBM 7090 FORTRAN program was written to read a preassigned mass-energy map from tape, set predetermined extraneous points to zero, and calculate statistical moments. Calculations are made with respect to both mass and energy of the zeroth through fourth origin and central moments, and the results are printed in tabular form. (Claudette Ruge for Eldon Haines)

A program has been written and debugged which fits, by least squares, experimental data to a given function of several variables. The functions given are eigenvalues of matrices. The program is now being run on the IBM 7090. (Thomas Clements for John Conway)

The energies and magnetic properties of low-lying crystal-field levels of PuCl_3 have recently been determined at this Laboratory. Published work indicates an anomaly in the temperature dependence of the magnetic susceptibility of this compound. Theoretical treatment of the magnetic properties of crystals has developed to such an extent that it should be possible to explain the magnetic-susceptibility anomaly in terms of the properties of the crystal-field levels. A calculation is being made as an attempt at such an explanation. (Edna Williams for Ralph McLaughlin)

A machine-language subroutine, SOFTLY, designed for use with FORTRAN programs, was written to provide buffered read-in and processing of magnetic tapes prepared by the ten-dimensional pulse-height analyzer. (Paul Concus for the Chemistry Group)

A 7090 version of the 704 FORTRAN program FRENIC was prepared. FRENIC is a program to fit decay data by sums of exponentials. (Gordon Sutherland for John Mahony)

A FORTRAN program was written to evaluate for various elements some functions occurring in range-energy relationships. (Barbara Levine for A. C. DeMildt)

On the assumption of prompt neutron emission from spontaneous fission, a FORTRAN program that computes the neutron energy spectrum and its moments for a preassigned nucleus was written for the IBM 7090. The calculations require tables of average binding energies, total excitation energies, and number of protons, all as functions of mass number. The program uses the neutron-level densities as defined by Cameron. The theory is based on the probability of getting a J th neutron of a tabulated energy, following $(J-1)$ neutrons of various probable energies; an exponential probability of getting a gamma ray is assumed. Along with the average number of neutrons and the variance of the neutron distribution, the probabilities of getting exactly J neutrons, the average gamma-ray energy, and the moments of the neutron spectrum are tabulated as functions of the J th energy levels for a given mass number. Runs have been made for Cf^{252} and U^{235} and mass numbers 80 through 159. The results are being compared with the experimental results reported by Bowman et al.²⁹ on the spontaneous fission of Cf^{252} . (Claudette Rugge for Douglas Milton)

The Los Alamos least-squares IBM 704 program for nonlinear parameters was converted for use on the IBM 7090 under Monitor control. This package was then applied to the specific problem of fitting data according to the radioactive decay function of $M \leq 10$ components. A special input routine was written to analyze the data as they are obtained from the experiment. The data include the number of counts at a specific time, the interval of counting time, and the background at this time. Given this, the program is designed to find best values for the number of atoms and the spontaneous-fission half life of the M isotopes. (Claudette Rugge for Ray Gatti)

By using the Los Alamos least-squares package for nonlinear parameters, a fitting function, obtained from the ratio of the McIntyre modified Blair model to the Rutherford formula for the differential cross section, was written in FORTRAN for the IBM 7090. This is a five-parameter model which is to be applied to heavy-ion elastic-scattering differential cross-section data obtained as a function of angle. (Claudette Rugge for Akira Isoya)

An IBM 650 code, HEAT, was written to evaluate a formula that calculates heat capacities from energy levels. (Noel Brown for Guenter Ahlers)

A program for use with the 7090 Monitor was written that determines eigenvalues and eigenvectors of a symmetric matrix and then calculates the Landé g factor. (Edna Williams for John Conway)

A 7090 FORTRAN program to do Monte Carlo integrations for the calculation of polarizations and differential cross sections in (d, p) reactions was written. (Edna Williams for Akira Isoya)

²⁹ Harry R. Bowman, Stanley G. Thompson, J. C. D. Milton, and Wladyslaw J. Swiatecki, Velocity and Angular Distributions of Prompt Neutrons from Spontaneous Fission of Cf^{252} , UCRL-9713-Rev., Dec. 1961.

A 650 program was written to calculate temperature from measured resistance in a germanium thermometer.

A 650 program to calculate temperature from measured vapor pressure of hydrogen was written. (Bert Albrecht for Guenter Ahlers)

A 650 FORTRAN program was written to determine the concentration of uranium, potassium, and thorium in sources of aggregate material for low-background shielding. (Bert Albrecht for Harold Wollenberg)

A 7090 FORTRAN program was written to punch cards from selected files of a magnetic tape. (Bert Albrecht for Ralph Korteling)

A 7090 FAP subroutine was written which will write at position J of output tape A3 the symbol stored at N, where $J = N + 19$. (Bert Albrecht for Norman Glendenning)

A least-squares program has been written which calculates a_i so that $R = \sum_j (y_j - \sum_i a_i e^{\lambda_i t_j})^2$ is a minimum. The λ_i are given. (Carl Quong for John Mahony).

Several three-dimension integrals arising in the calculation of polarization and differential cross sections in d, p reactions were evaluated approximately for the Nuclear Reactions Group. A Monte Carlo technique was used. (Paul Concus for the Nuclear Reactions Group)

Changes were made in the program TAPER,³⁰ used by the Nuclear Chemistry Group in processing data tapes recorded by the pulse-height analyzer. The changes allow optional use of the 7090 cathode-ray tube to provide automatic plots of data formerly given only in tabular form. (Paul Concus for the Nuclear Chemistry Group)

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

III. Biology and Medical Physics

An IBM 709 program was written to compute and plot on the CRT numerical solutions for the ordinary differential equation systems

$$\dot{A} = k_{BA} B - k_{AB} A,$$

$$\dot{B} = k_{AB} A - k_{BA} B - k_{BC} B (P-C),$$

$$\dot{C} = k_{BC} B (P-C) - k_{CD} C$$

and

³⁰ Previously described in Physics Division Semiannual Report, UCRL-10349, May 1962, p. 41.

and

$$\dot{M} = k_{MN} M (P-N)$$

and

$$\dot{N} = k_{MN} M (P-N) - k_{NO} N,$$

relating to phagocytosis in the intact animal. The Runge-Kutta method was used with an automatic but limited adjustment of the integration step. Computation was performed for eighteen choices of the set parameters k_{AB} , k_{BA} , k_{BC} , k_{CD} , k_{MN} , and k_{NO} and for seventeen sets of initial conditions $A(0)$, $B(0)$, $M(0)$, and $N(0)$. (Jonathan Young for Howard G. Parker, Medical Services)

Mathematical formulations were developed for calculating the distribution of radiation dosage received by persons medically irradiated at the Lawrence Radiation Laboratory cyclotron facility. (Grove Nooney for John Lyman of the Tobias Group)

Two FORTRAN programs were written to tabulate radiation dosages received at certain grid points during irradiation of the brain (especially the pituitary) with a high-energy proton beam from the 184-inch cyclotron. These tables are used in the preparation of isodose contour maps. (Dave Stevens for John Lyman)

An IBM 650 code, RAT TEST, was written in connection with an experiment to determine the effect of radioactivity on rats. This program computes various statistical functions by using the data obtained from the experiment. (Noel Brown for Pat Durbin)

A simulation program was designed for the IBM 7090 in order to determine the neutron flux through earth and air at a point at a given distance from a neutron source (for which the energy-emission spectrum is known). (Grove Nooney for Lloyd Stephens of the Health Physics Department)

BAYOU

BAYOU is part of a project aimed at automating the measurements and analysis required in medical radioactive-tracer experiments.

A number of programs will be required in this project:

a. Program HEART This program to analyze data on arterial blood flow has been completed and tested. One set of test data has been successfully processed. Some further modifications to the program are now being made, and extensive testing will follow.

b. A program to be used for compartment analysis of tracer experiments is being obtained from Dr. M. Berman (National Institute of Health). Minor modifications will be made to adapt the program for use with our FORTRAN Monitor system. The program may prove useful to several members of the Radiation Laboratory.

c. A library program for use with the proposed automatic measurement and recording system is in the planning stage. (Mark Horovitz for Dr. M. Pollycove)

AGE

AGE is an attempt to represent the aging process in a human population so as to furnish a connection between physiological measurements and disease statistics.

The following preliminaries to this investigation have been completed:

- a. Data concerning the effects of radiation on aging have been reviewed so that they may be used as a test of the proposed representation.
- b. The properties of the matrix representation used have been investigated.
- c. The steps required to complete this investigation have been outlined.
- d. A scheme for data processing and analysis of physiological measurements as a function of age has been constructed and will be submitted to the National Institute of Health for comment. (Mark Horovitz for Roger Wallace and Gordon Kepner)

IV. Mathematics and Computing

Work has been done as follows to prepare general utility programs.

The Legendre Polynomial subroutine used in the IBM 650 General Least-Squares Routine³¹ has been revised. The original Legendre subroutine generated erroneous values for $P_n(0)$, $n > 0$. (Edna Williams for Edwin Towster)

A Los Alamos salary-analysis program, WILD, was revised so that it could be run under the new 7090 FORTRAN system. (Edna Williams for Paula DeLuca)

A modification of the Library program VARMINT (Variable Metric Minimization program) has been begun. The current program needs safeguards against too many lines of output, as well as other small changes. (Joe Good for Harold Hanerfeld)

Several subroutines for the 1401 system were written, including:

- a. a general-purpose BCD or BINARY (or both) tape duplicate,
- b. a general purpose BCD or BINARY (or both) tape dump, with BINARY tapes dumped in octal notation,
- c. a program to print a table of 1401 numeric addresses, and corresponding alpha-numeric codes,
- d. a subroutine to generate 1401 test pattern tapes, and
- e. a subroutine, not completed, which will merge various sequences of an arbitrary number of files from two different tapes onto a third tape. (Gordon Sutherland for James Baker and Kent Curtis)

³¹ Lester K. Goodwin, General Least-Squares Program for the IBM 650 Computer, June 14, 1960, UCRL-9263.

Work was completed on a system of seven 1401 programs to do time-card accounting for the computing group. These include:

- a. an initialization program,
- b. a program that sorts time cards by account number and problem name,
- c. a program to record time cards on a Master Tape and print out a report of time assigned and time remaining for each account number on each machine,
- d. a program to make insertions, deletions, and corrections to the Master Tape,
- e. a program to enter weekly assignments of time available to each account number on each machine,
- f. a program to prepare and print the monthly time report (two versions), and
- g. a program to prepare and print a summary of time used on any machine or combination of machines, between any two dates (0800-0800) by any account number or any problem name (or by all account numbers and all problem names), operating under any one system (or under all systems).

The SHARE subroutine D1 AR SMP2 (Simpson's Rule Integration routine) was modified to run on the FORTRAN Monitor.

A FORTRAN program was written to solve the equation $A\bar{x} = y$, where A is a large matrix (order ≈ 900) such that

- (a) A can be represented in a "three-block" scheme, the diagonal blocks having order ≤ 30 , and
- (b) A satisfies certain convergence criteria. (Dave Stevens)

Some least-squares subroutines were analyzed and tested to determine their accuracy and speed. We found that the program MLR (minimize linear residuals), written by R. E. Von Holdt, which uses double-precision arithmetic, was the most accurate and fastest of the programs tested. The method used in MLR is premultiplication by unitary matrices. (Carl Quong)

A modification, ZO EO Z017, to Library Program VARMINT was completed. VARMINT is a minimization program used to fit a function to data points (where the user must supply the function and derivatives). This modification provides an option for checking that the coded derivatives are correct.

Modification ZO EO Z018 was begun on library Program VARMINT to allow VARMINT to numerically calculate the derivatives when it is impossible for the user to supply them. This may be used for phase-shift analysis.

Assistance was given to and some programming was done for various members of the Laboratory, specifically Mark Horovitz and Jim Lindsey of the Alvarez Group, Russel Batt and Gunther Ahlers of the Inorganic Research Group on Campus, Julius Solomon and Dick Kurz of the Moyer Group, John Mahony of the Chemistry Group, and Ralph McLaughlin of Nuclear Chemistry. (Joe Good)

Work was begun on solving a set of nonlinear partial differential equations by a perturbation technique. The equations arise in the field of fluid mechanics in the theory of finite-amplitude standing capillary-gravity waves.

Work was completed on the numerical calculation of the roots and weight coefficients for Gauss-Laguerre quadrature formulas to evaluate integrals that behave like $X^B e^{-X}$ times a polynomial in X , for $B = -1/4, -1/2$, and $-3/4$. To achieve the desired accuracy, an existing SHARE triple-precision arithmetic package was revised to be compatible with the LRL 7090 FORTRAN Monitor system and was used for the calculations. Participants at LRL in the National Science Foundation summer program of Research Participation for High School Teachers completed a portion of the necessary programming as their project. A paper, "Tables for the Evaluation of $\int_0^\infty x^B e^{-x} f(x) dx$ by Gauss-Laguerre Quadrature" is being submitted for publication to Mathematics of Computation.

A subroutine J4 EO CONV was written for use with FORTRAN double-precision programs. It provides for output of a double-precision floating-point variable to sixteen significant digits.

Work was completed on solving a set of nonlinear partial differential equations arising in the field of fluid mechanics, and a paper, "Standing Capillary-Gravity Waves of Finite Amplitude," was submitted for publication in the Journal of Fluid Mechanics.

Work was completed on a paper on "Effects of a Magnetic Field on Natural Convection in a Toroidal Channel." The paper was presented to the Annual Winter Meeting of the ASME and will be published in the Journal of Applied Mechanics in 1962.

A series of lectures on tensor analysis was prepared and delivered to members of the Mathematics and Computing Group. Also, a series of lectures on the subject of advanced FORTRAN was prepared at the request of the Computer Center on the Berkeley Campus and delivered on the Campus. (Paul Concus)

The 7090 program, GENMOM (formerly GENPCM), a particle-interaction simulation program for the 7090 computer, has been improved and generalized. A 7090 program, WHOOPS, which uses GENMOM to calculate certain distributions of angles and effective mass in phase space, has been written. WHOOPS was used also to check the accuracy of other programs performing phase-space calculations. (Grove Nooney for Gerry Lynch and Mark Horovitz)

Research was begun on solving, by variational means, nonlinear systems of ordinary differential equations with boundary and interior point conditions.

Mathematical assistance was given in statistics, differential equations, and the variational determination of quantities associated with differential and integro-differential equations (the last, particularly for the liquid-drop model of the nucleus). A series of six one-hour lectures on the hypergeometric differential equations was prepared and delivered primarily to members of the Mathematics and Computing Group. (Grove Nooney)

A report was issued: Jonathan D. Young, Application of Linear Programming to the Numerical Solution of Linear Differential Equations (Thesis), UCRL-10110, March 1962.

V. Computer Operations and Systems Programming

Operations

During the past six months, utilization of the 7090 computer by Berkeley Research Groups increased from one to four shifts per week. The 709 Computer continued utilization until October 1 at a rate of four shifts per week.

A system of scheduled FORTRAN Monitor runs of short production problems and debugging shots was instituted on the 7090 computer. This system reduced the turn-around time for such machine runs to an average of about 2 hours.

Computer facilities in Building 50-A were completed. An Input/Output Area, Tape Storage Area, and a Ready Room were in use in this building during most of this time.

On October 1, 1962, the Laboratory accepted a grant from IBM of machine rental on all major components of the 709 computer for the coming year. Under the terms of this grant, the 709 computer is to be used exclusively in conjunction with the development of on-line measuring and pattern-recognition systems. Systems of this sort currently under development include QUEST and SMP.

On October 1, the Laboratory began to purchase significant amounts of time on the 7090 Computer installed at the Campus Computer Center. It is expected that this use of the Campus 7090 will continue throughout the remainder of FY 1963.

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

During the next months, the Laboratory 7090 computer will be converted to a 7094 and an additional 32,000 words of core storage will be installed on it. (Marvin Atchley and Paul Rhodes)

Systems Programming

During the past half year, the Systems Programming effort was in the following areas:

- a. maintenance and modification of existing 709 and 7090 Systems Programs,
- b. planning Systems Programs to handle additional hardware to be installed on the 7090,
- c. planning and implementing Systems Programs to solve multi-programming problems associated with the operation of one-line measuring equipment, and

d. extending and refining 1401 Systems Programs.

Extensive modifications were incorporated in the FORTRAN Compiler Program and the FAP Assembler. A final version of the SOS Machine Language Programming System was prepared. It is hoped that during the coming months, use of the SOS System will decrease markedly and that, hence, the necessity for maintenance of that system will disappear. (Donald Zurlinden, Douglas Brainard, and Isabel Blandford)

A set of subroutines for the use of the CRT Recorder on the 7090 computer was completed during the past six months. These subroutines are compatible with similar subroutines for the 709. They enable the user to prepare a wide class of graphical output on the CRT Recorder. (Ralph Jones)

Specifications were prepared for a new CRT Display and Recorder System which is proposed for installation on the 7090 computer. This new system is designed to allow on-line interaction between the computer and its users. Plans were made for Systems Programs which would allow this new equipment to be used effectively.

It was decided to make the following modifications to the Berkeley 7090 computer:

- a. convert it to a 7094,
- b. convert all Tape Drives from 729 MOD IV's to 729 MOD VI's,
- c. install 1301 Disc Files, and
- d. add an additional 32,000-word module of memory.

The last two of these modifications have extensive implications for the Systems Programs that are to be used with the 7090. The additional core memory module will be used to facilitate the simultaneous on-line operation of measuring equipment and the operation of standard computational programs.

In cooperation with the SMP Group, this group made design studies for multiprogramming systems for the 7090 and other computers. The goal was the design of systems whereby devices such as the SMP with relatively low input rates and analysis requirements could be used economically on large-scale computers. Systems were designed which, it is felt, can achieve that goal. Because of the continuing availability of the 709 computer, the immediate need for such systems has been somewhat relaxed.

Machine coding and debugging of a programming system for the 1301 Disk Memory, which is to be installed on the 7090 computer early in January, is nearly complete. The 1301 System will be used for two principal purposes at the Laboratory: for storage of programs and programming systems, and as scratch storage during the execution of data-processing programs involving large quantities of data to which random access is required.

Preparations were initiated for the installation of the IBSYS Monitor Systems and the FORTRAN IV Compiler System late during the next report period. (Isabel Blandford, Douglas Brainard, Myron Myers, and Donald Zurlinden)

A special-purpose 1401 Tape Sort-Print program was written to process certain types of print tapes from the FOG System. The print tape to be processed consists of one file of n pages that are out of sequence. The program outputs n pages in sequence--the ordering being done on the basis of order numbers found in the first line of each page.

A 1401 tape-to-printer program was written to handle print tapes that may contain several print lines in one physical record. Although usable for other types of print tapes, this program is primarily designed to facilitate the handling of FORTRAN Monitor output.

A program for converting paper tape to magnetic tape has been written for the 1401 system. Once on magnetic tapes, data may be used as input to 709-7090 programs.

A "tape-compare" program designed to detect and indicate differences between pairs of tapes has been written. Records on tapes to be compared must not exceed 500 words in length.

All the 1401 programs described above have been incorporated in the 1401 system tape. (Walter Hutchinson and Fran Permar)

PHYSICS RESEARCH

Edward J. Lofgren in charge

INTERACTION STUDIESK⁻ - Proton Interactions

Edgar F. Beall, William Holley, Denis Keefe, Leroy T. Kerth,
John J. Thresher,* Ching L. Wang, and William A. Wenzel

The analysis of the data collected on K⁻ - proton interactions is continuing. A total of 360,000 spark chamber pictures was taken for incident K⁻ momentum between 700 and 1400 MeV/c. About 5% of these pictures have been scanned for elastic scatterings only. Each event was fitted to coplanarity and opening-angle requirements by using kinematics tables and stereographic plots. About 120 events at each of ten different momenta were accepted as elastic scatterings in this preliminary sample. The angular distributions were fitted with the power series $d\sigma/d\Omega = \sum_n A_n \cos^n \theta$. In the region of the resonance (1050 MeV/c) the results of the fitting procedure indicate a vanishing A_6 over the entire energy region studied. A plot of the A_n for fifth-order fits as a function of momentum shows that A_4 and A_5 have significant peaks near the resonant energy (1050 MeV/c). The most probable spin assignment for the resonance, based on this preliminary sample, is $F_{5/2}$ or $D_{5/2}$.

The analysis of all the film for elastic scatterings by use of the SCAMP system is under way. An IBM-7090 program for elastic scattering has been written and is ready for use.

A study of the charge-exchange interaction $K^- + p \rightarrow K^0 + n$ has been begun. An IBM 7090 computer program now being written will fit events to each of the reactions



and



where the missing mass X is to be determined. Preliminary studies indicate that a separation of the events in category (1) from those in (2) will be possible. We expect to have a few hundred events at each of several momenta.

*Work done while on leave from the Rutherford High Energy Laboratory, Harwell, Didcot, Berkshire, England. Dr. Thresher has now returned to Harwell.

π - π Interaction

Denis Keefe, Leroy T. Kerth, Carl M. Noble, John J. Thresher,*
William A. Wenzel, and Theodore F. Zipf

This experiment is designed to study final-state correlation between pions in pion-nucleon interactions. A total of 700,000 spark chamber pictures was taken during the run at the Bevatron that ended in June 1962. The data were taken at 2.0, 3.0, and 4.0 BeV/c incident pion momenta. The necessary IBM 7090 computer programs to calculate optical distortions, three-dimensional orbits through the Sagane magnet, kinematics (the spark chamber equivalent to KICK-GUTS), and geometrical corrections are being written.

Preliminary scanning is under way to evaluate the data and develop scanning procedures.

 π^+ - Proton Elastic Scattering at 1.5, 2.0, and 2.5 BeV/c

Victor Cook, Bruce Cork, and William R. Holley

The analysis and discussion of the data have been completed. A description of the results of the angular-distribution measurements was given in the preceding semiannual report. Predictions of the theories for elementary particle poles and Regge poles were compared with the measured angular distributions near $\cos\theta^* = -1$. The elementary neutron-exchange pole contributed approx 90 mb/sr at 2.0 BeV/c, where the measured value was approx 0.4 mb/sr. In the Regge-pole analysis, the value $\alpha = -0.8$ was taken for the neutron trajectory and the "form factor" $b(u)$ was calculated from the measured values of $d\sigma/d\Omega$. We found

$$b(u) = 135 \pm 16 \text{ mb at } 1.5 \text{ BeV/c,}$$

and

$$64 \pm 12 \text{ mb at } 2.0 \text{ BeV/c,}$$

$$45 \pm 15 \text{ mb at } 2.5 \text{ BeV/c.}$$

The values of $b(u)$ at 2.0 and 2.5 BeV/c are equal within one standard deviation, in accord with the requirement that b should not be a function of incident momentum. Because of the approximations required to make this analysis possible, this result is only weak support for the Regge hypothesis, which predicts variable angular momentum for the neutron. A more comprehensive experiment, which could settle this question, is being proposed.

 K^+ - Proton Interactions

Victor Cook, Denis Keefe, Leroy T. Kerth,
William A. Wenzel, and Theodore F. Zipf

The analysis and discussion of the data have been completed and reported. An account of the results was given in the preceding semiannual report. Manuscripts for publication were completed during the period covered by this report.

* Work done while on leave from the Rutherford High Energy Laboratory, Harwell, Didcot, Berkshire, England. Dr. Thresher has now returned to Harwell.

SPARK CHAMBER TESTS AT LOW TEMPERATURE

Edgar F. Beall, Victor Cook, and Theodore F. Zipf

A program to study the feasibility of operating spark chambers at low temperature was begun. The ultimate goal is a chamber that can operate at liquid hydrogen temperature. Because of the technical difficulties inherent in developing a system containing hydrogen and electrical sparking apparatus, it was felt that a test at liquid nitrogen temperature would be a useful first step.

A five-gap aluminum plate chamber was placed in a tank containing helium gas, which was surrounded by a liquid nitrogen jacket. The spark chamber pulse was provided by a hydrogen thyratron pulser. Cosmic ray particles were used in this test. Because of the low counting rate our results are mainly qualitative; however, they do indicate that good sparking efficiency in helium at liquid nitrogen temperature and 1 atm gas pressure can be achieved with gradients of the order of 25 kV/cm. The next test will require a liquid hydrogen flask that can accommodate a spark chamber plate assembly.

We have also begun tests to determine if helium bubbles can be introduced into liquid hydrogen and if a glow discharge can be initiated in the ionized gas by applying a high-voltage pulse across two plates in the liquid hydrogen, between which the bubbles are moving. We are now developing a "bubbler" that will squirt small helium bubbles into the gaps of a spark chamber placed in a flask of liquid hydrogen.

BERKELEY LINEAR ELECTRON ACCELERATOR: OPERATIONS

Douglas W. Pounds

During the period May through October, beam time for experimenters amounted to 342 hours or about 31% of the available time. The remainder of the time was devoted to (a) modification of the machine for an increase and improvement in performance, (b) extensive modification of the facility in preparation for new long-term experimental programs, and (c) setup for experimenters.

The principal groups utilizing the machine for this period were Plasma Physics, Radiation Chemistry, U. C. Soils and Plant Nutrition, Bio-Organic Chemistry, Health Physics, NASA (via Bio-Organic Chemistry), and U. S. Department of Agriculture.

Machine modification was primarily directed toward increasing the maximum energy from 5 MeV to 10 to 12 MeV. These modifications are mostly complete, with final testing dependent upon acquisition of new 5-MW rf windows. Other modifications include new beam-monitoring equipment, alterations in the safety-interlock system, and some incidental changes.

Facility modifications included rearrangement of existing space and an increase in ac, dc, monitoring, water, and gas lines. A further increase in working space (about 40%) to meet new experimenter requests is just beginning.

The outlook for the coming 6-month period is for a substantial increase in beam time due to the addition of several long-term experimenters, the completion of the modification and testing for a 10- to 12-MeV machine capability, and an increase in working area and in experimenter facilities.

PUBLICATIONS

1. Victor Cook, Denis Keefe, Leroy T. Kerth, Paul G. Murphy, William A. Wenzel, and Theodore F. Zipf, Elastic K^+ -Proton Scattering at 970, 1170, and 1970 MeV/c, Bull. Am. Phys. Soc. 7, 469 (1962); UCRL-10183, Sept. 1962), submitted to Phys. Rev.
2. Edgar F. Beall, William Holley, Denis Keefe, Leroy T. Kerth, John J. Thresher, Ching L. Wang, and William A. Wenzel, Cylindrical Spark Chamber Array for the Measurement of Angle, Range, and Polarization in a Study of K^- -p Interactions, UCRL-10249, May 1962.
3. Denis Keefe, Leroy T. Kerth, Carl M. Noble, John J. Thresher, and William A. Wenzel, A Magnetic Spectrometer Using Spark Chambers to Obtain Large Solid Angle and High Resolution in π - π Interaction Studies, UCRL-10250, May 28, 1962.
4. Edgar F. Beall, William Holley, Denis Keefe, Leroy T. Kerth, John J. Thresher, Ching L. Wang, and William A. Wenzel, Elastic K^- -p Scattering Between 700 and 1400 MeV/c, presented by D. Keefe at the Conference on High-Energy Physics, CERN, 1962 (UCRL-10222 Rev., Aug. 1962).
5. Victor Cook, Bruce Cork, William R. Holley, and Martin L. Perl, Elastic Differential Cross Section of π^+p at 1.5, 2.0, and 2.5 BeV/c (UCRL-10391, Sept. 1962), to be published in Phys. Rev.

PHYSICS RESEARCH

Burton J. Moyer and A. Carl Helmholtz in charge

PION PRODUCTION BY PIONS INCIDENT ON PROTONS

Barry C. Barish, Richard J. Kurz, Victor Perez-Mendez, and
Julius Solomon

Analysis of the data from the following experiments performed at the 184-inch cyclotron has been continued.

Reaction $\pi^- + p \rightarrow$	Incident energy (MeV)	Method	Date of experiment
(a) $\pi^+ \pi^- n$	365 432	π^+ detection	August 1960
(b) $\pi^- \pi^0 p$	310 377	p detection	March 1961 August 1961
(c) $\pi^- \pi^+ n$	374	n detection	December 1961
$\pi^0 \pi^0 n$	417 454		

The general features of the data reported previously have not changed. Corrections to the data of these experiments are being computed in more detail.

NUCLEAR EXCITATION FROM μ^- - MESON CAPTUREJagdish Baijal, Justo Diaz, Donald E. Hagge, Selig N. Kaplan, and
Robert V. Pyle

The neutron energy spectra from nuclear capture of μ^- mesons have been measured for Al, Ca, Fe, Ag, I, Au, and Pb.

The experiment was performed in the meson cave of the 184-inch cyclotron. The detector was a liquid scintillator in conjunction with a pulse-shape discriminator. Measurements with D-T, Pu-Be, and mock-fission sources indicate good reproduction can be obtained from a first-collision theory with hydrogen alone.

The neutron energy spectra have been obtained from the proton pulse-height spectra with the aid of a computer program. Calculations of the directly emitted neutron spectra are being made. When this contribution is subtracted from the total spectra, the resulting evaporation spectra should furnish the nuclear temperatures. Information on nuclear excitations will be obtained when these data are analyzed, in conjunction with previously measured neutron multiplicity distributions, in terms of a nuclear model.

PROTON POLARIZATION IN ELASTIC π -p SCATTERING

Richard Eandi, Thomas J. Devlin, Robert W. Kenney,
Paul G. McManigal, and Burton J. Moyer

A spark chamber experiment was performed in the Fall of 1961 to study the polarization of recoil protons at pion energies between 500 and 1000 MeV. The film taken is about 80% scanned, and all film analysis will be completed in a few months.

With the present available data on the analyzing power of carbon, tentative results for the recoil-proton polarization as a function of pion scattering angle have been calculated for pion energies between 500 and 700 MeV. Examples of polarization data obtained for π^- scattering are as follows.

Polarization, P, as a function of scattering angle

$\cos \theta_{\pi}^*$ (deg)	Energy (lab) (MeV)		
	520	570	690
0.30	-0.98 ± 0.15	-0.38 ± 0.20	-0.24 ± 0.20
-0.30	0.44 ± 0.20	0.62 ± 0.30	0.30 ± 0.20

To completely analyze the film data for pion energies above 700 MeV, data are needed for the analyzing power of carbon at higher energies. To obtain this, a calibration experiment using a proton beam of known polarization and involving the same spark chambers is now being performed at the cyclotron. Upon the analysis of the latter data rests the remaining analysis of the pion experiment.

A digitized-protractor scanning system is also being developed to facilitate scanning and analysis and is expected to be in operation to aid in scanning the calibration experiment.

PHASE-SHIFT ANALYSIS IN π -p SCATTERING

Robert J. Cence

We are just now beginning a phase-shift analysis of π^{\pm} -p from 530 MeV to 1.6 BeV, using the program previously described. The data for $\pi^{\pm} + p \rightarrow \pi^{\pm} + p$ are those of Helland, Moyer, et al. In addition we are going to use the recoil-proton polarization data for the same reactions of Eandi, Moyer, et al. as they become available. (Some are already available.)

Preliminary work on π^+ -p at 530 MeV shows that if one uses partial waves up to and including F waves and demands that the real part of the $S_{1/2}$ and $P_{1/2}$ phase shifts be negative and that the real part of the $P_{3/2}$ phase shift lie between 140 deg and 190 deg, then one gets only a few acceptable solutions. These constraint conditions are minimal and appear to be clearly indicated by data at lower energies.

Contrary to our previous report, we have decided against doing over again the phase-shift analyses at all lower energies. The reason is that the available data do not have nearly enough precision to make such an analysis meaningful. We feel that the experiments in the energy region from 0 to 300 MeV could well be done over again with the much greater precision available by the methods in current use.

POLARIZATION IN NUCLEAR SCATTERING OF 740-MeV PROTONS

Richard D. Eandi, Selig N. Kaplan, Robert W. Kenney,
Paul McManigal, and Vincent Peterson

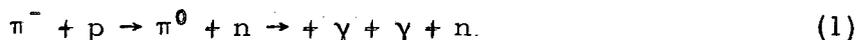
The polarization in proton-nucleus scattering is being measured at the full energy of the 184-inch cyclotron. This polarization is being measured from the asymmetry from double scatterings both external to the cyclotron. Eight different elements are being used as target materials, including hydrogen, helium, and carbon. In order to insure the elasticity of the scatterings, the protons are being momentum-analyzed, after scattering, by a magnetic spectrometer.

Original motivation for this work stemmed from our work at the Bevatron concerning polarization in π -p scattering. We had used spark chambers with carbon plates to analyze the polarization of these protons, and decided to calibrate these chambers at the cyclotron. Lack of data in this energy range, including proton-proton polarization, added motivation. Since conception, this program has blossomed into a most interesting series of measurements. Because the polarization is different for protons scattered elastically and inelastically, momentum analysis was deemed necessary after the second scattering. The biggest innovation in technique is measuring the scattering only to the left at the second scatterer, but both left and right at the first scatterer. This is to decrease systematic errors and avoid moving the analyzer, which is capable of resolving a few MeV, while deflecting 140-MeV/c protons through 102 degrees.

RADIATIVE CAPTURE OF π^- IN FLIGHT

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

A. An experiment has been done at the 184-inch cyclotron to study the reactions



and



at an incident pion kinetic energy of 50 MeV. The experimental data will provide information about the low-energy behavior of pion-nucleon phase shifts.

The energy spectrum of γ rays from Reactions (1) and (2) has been measured at a laboratory-system angle of (84 ± 5) deg by using a total-absorption counter. [This counter has been described in Rev. Sci. Instr. 33, 741 (1962), and has a measured resolution of $\pm 6\%$ at 129 MeV.] The data are now being analyzed.

B. The apparatus used for the experiment described in A has also been used to study the interactions of 50-MeV negative pions in deuterium. The energetically possible reactions are



and



Reactions (3) and (4) may be detected by measuring the energy spectrum of γ rays, as in A above.

It is not yet certain that the cross section for Reaction (5) can be obtained from our present data. Analysis of the data is in process.

C. In the course of our cyclotron work we have developed a low-energy pion beam with the following characteristics:

$$\text{Momentum spread, } \frac{\Delta P}{P} = \pm 6\%;$$

Beam spot size (full width at half maximum), horizontal 2.2 in., and vertical 2.0 in.

T_π	Flux = F (10^6 min)	F_π	Composition of beam	
			F_μ	F_e
30	0.7	0.60	0.10	0.30
50	2.5	0.70	0.10	0.20
70	3.0	0.80	0.08	0.12

For studying low-energy pion beams we have developed instrumentation enabling us to use several techniques of measuring the beam composition that are more rapid than the conventional one of measuring range curves. These techniques, with their approximate range of usefulness and the "state of the art" of their instrumentation, are listed below.

- (a) dE/dx : $T_\pi \leq 50$ MeV, plastic scintillator, 1 in. thick, resolution approx 8;
- (b) Time of flight: $T_\pi \leq 50$ MeV, $T_{res} = 1.10^{-9}$ sec;
- and
- (c) Cerenkov threshold: $T_\pi > 50$ MeV, styrene cell, 12 in long.

[Methods (a) and (c) are facilitated by the use of a multichannel pulse-height analyzer.]

PAPER ISSUED

Jerome A. Helland, Thomas J. Devlin, Donald E. Hagge, Michael J. Longo, Burton J. Moyer, and Calvin D. Wood, Angular Distributions in $\pi^{\pm}(-p)$ Elastic Scattering in the Range 500 to 1600 MeV(UCRL-10478, Sept. 1962), submitted to Phys. Rev. Letters.

PHYSICS RESEARCH

William A. Nierenberg in charge

ATOMIC BEAM GROUP

Howard A. Shugart

The Atomic Beam Group continues to devote most of its effort toward the systematic measurement of various atomic and nuclear properties of radioactive isotopes. Some of the properties measured are nuclear spins, nuclear magnetic dipole and electric quadrupole moments, atomic hyperfine structures and hyperfine-structure anomalies, and electronic g factors. Many of these properties serve two useful functions in nuclear physics. First, they form test information for theories of the nuclear ground state. Second, nuclear spins act as a base for constructing decay schemes in beta- and gamma-ray spectroscopy.

Papers Issued

1. Vernon J. Ehlers and Howard A. Shugart, Hyperfine-Structure Separations and Nuclear Moments of Gallium-68, *Phys. Rev.* 127, 529 (1962).
2. Y. W. Chan, W. B. Ewbank, W. A. Nierenberg, and H. A. Shugart, Nuclear Spin of 9.5-hr Au^{196m}, *Phys. Rev.* 127, 572 (1962). (This is the largest directly measured nuclear spin, $I = 12$, for Au^{196m}.)
3. H. A. Shugart, Summary of the New Published Measurements from the Atomic Beam Group at the University of California from Oct. 1960 to April 1962, presented at Sixth Brookhaven Conference on Molecular Beams, June 11-13, 1962.
4. E. D. Commins and D. Dobson, Measurement of the Nuclear Moment of Neon-19 by Observation of the Asymmetry in the Positron Decay of Polarized Nuclei, presented Sixth Brookhaven Conference on Molecular Beams, June 11-13, 1962; D. A. Dobson and E. D. Commins, Measurements of the Nuclear Moment of Ne¹⁹, *Bull. Am. Phys. Soc.* 7, 475 (1962).
5. Yau Wa Chan, The Nuclear Spins and Magnetic Moments of Ag¹¹², Ag¹¹³, Au¹⁹⁴, Au¹⁹⁶, and Au^{196m} (Ph. D. thesis), UCRL-10334, June 1962.
6. W. Bruce Ewbank and Howard A. Shugart, Hyperfine-Structure Measurements on Silver-105 (UCRL-10406, Aug. 1962), submitted to *Phys. Rev.*

PHYSICS RESEARCH

Wilson M. Powell and Robert W. Birge

INTERACTION STUDIES

Beta Decay of Hyperons

Robert P. Ely, George Gidal, G. Kalmus, Wilson M. Powell, and
William J. Singleton

The stopping K^- film has been scanned for Λ -hyperon decay branching ratio

$R = \frac{\Lambda \rightarrow p + e + \bar{\nu}}{\Lambda \rightarrow N + \dots}$. A preliminary paper on this work, published in the Proceedings of the 1962 International Conference on High-Energy Physics at CERN, reports the ratio as $(1.0 \pm 0.03) \times 10^{-3}$, based on 126,000 visible Λ decays. This ratio is considerably lower than that predicted theoretically,¹ and also lower than the experimental values published by others.^{2, 3}

Since the preliminary paper, the scanning has been completed and 106,000 additional lambdas have been found. The final analysis is not yet complete. Groups from the University College, London, and the University of Colorado are participating in this work.

K^+ -p Elastic Scattering

George Gidal and Warner Hirsch

In the K^+ -p elastic-scattering experiment at 910 MeV/c in propane, results have been obtained on 879 events (about 85% of the total). The angular distribution can fit the cosine series $(1 + a \cos \theta)$, where $a = 0.20 \pm 0.05$. Polarization measurements using proton-proton and proton-carbon recoils were made. A phase-shift analysis incorporating these polarization data is currently being carried out.

π^+ -p Scattering at 600 MeV

Peter Newcomb

We have taken 18,000 pictures with the 15-in. hydrogen bubble chamber in a separated π^+ beam at 725 ± 13 MeV/c. The pictures were scanned, and the following numbers of events were obtained:

¹R. P. Feynman and M. Gell-Mann, Phys. Rev. **109**, 193 (1958).

²W. Humphrey et al., Phys. Rev. Letters **6**, 478 (1961).

³B. Aubert et al., in Proceedings of the Aix-en-Provence International Conference (Centre d'Etudes Nucléaires, Saclay, 1961), Vol 1, p. 197.



In all the film only five events, excluding events with Dalitz pairs, were found with more than two outgoing prongs. Therefore, double-pion production was ignored.

The angular distribution for the elastic events was fitted with a fourth-order polynomial in the cosine of the scattering angle.

The ratio obtained between Reactions (2) and (3),

$$(p + 0) / (n + +) = 5.6 \pm 0.7,$$

is in qualitative agreement with the value 6.5 predicted by the isobar model of Sternheimer and Lindenbaum.¹ In Reaction (2), both the momentum spectrum of the π^+ and that of the π^0 agree more closely with the isobar model than they do with phase-space calculations. The destructive-interference effect predicted by Bergia, Bonsignori, and Stanghellini² was not present.

These data were presented at the August 1962 meeting of the American Physical Society.³

Pion-Pion Resonances

Zaven G. T. Guiragossian

We have recomputed our 3.3-BeV/c $\pi^- + p$ data from the 72-inch hydrogen bubble chamber, using the new FOGV data-reduction program and improved optical constants. The main difference is to increase the effective magnetic field by 10%.

A study of the momentum transfer to the nucleon in the reactions



and



shows the predominance of the single-pion-exchange mechanism. The Yang-Trieman test gives isotropy up to $\Delta^2/\mu^2 \approx 4.5$. The π - π spectrum from constrained events of Reactions (1) and (2) shows the ρ resonance at $M_\rho = 770$ MeV with $\frac{\Gamma}{2} = 75.0$ MeV. We are examining the data to determine whether there are other resonances.

Preliminary data were presented at the Washington meeting of the American Physical Society, 1962 (Bull. Am. Phys. Soc. 7, 281 (1962)).

¹R. M. Sternheimer and S. J. Lindenbaum, Phys. Rev. 109, 1723 (1958).

²S. Bergia, F. Bonsignori, and A. Stanghellini, Nuovo Cimento 16, 1073 (1960).

³P. Newcomb, Bull. Am. Phys. Soc. 7, 468 (1962).

Study of Three-Pion and Four-Pion Mass Spectrum

Zaven G. T. Guiragossian and Thomas Schumann

We have looked at π^- -p interactions in the 72-inch hydrogen chamber with a beam momentum of 3.3 ± 0.1 BeV/c.

The following four-pronged reactions are being studied:

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

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

and

$$\pi^- + p \rightarrow \pi^- + \pi^- + \pi^+ + \pi^+ + n. \quad (3)$$

We have taken those events that were readily separable into one and only one of the above reactions and plotted the effective mass of all combinations of 2, 3, and 4 particles for Reactions (2) and (3). In this category there are 289 events for Reaction (1), 329 for reaction (2), and 273 for Reaction (3). Of particular interest (because of the speculated Pomeranchuk particle) is the $\pi^+\pi^+\pi^-\pi^-$ combination in Reaction (3). With the data analyzed so far, no obvious peak has been found. The ω and $N_{3/2}^*$ resonances are observed.

Double Hyperon Production in Deuterium

Robert W. Birge, George Gidal, and Sedong Kim

We are studying double hyperon production by 1.53-BeV/c K^- mesons on deuterium in the 72-inch chamber. Scanning of the 25,000 pictures taken is half completed, and measurements of potential candidates are under way.

Sigma-Hyperon Production

Yu Li Pan

The 1.15-BeV/c K^- film has been scanned for sigma hyperons in an attempt to look for sigma-pion resonances. Of particular interest is the $T = 2$ resonance predicted by the global-symmetry theory.¹ We chose to study the reactions

$$K^- + n \rightarrow \Sigma^+ + \pi^\pm + \pi^-$$

and

$$K^- + n(c) \rightarrow \Sigma^\pm + \pi^\mp + \pi^- + p$$

for the possible existence of this resonance.

Also of interest are (a) the production cross sections of Σ in propane, and (b) the polarization of Σ^+ .

The scanning and measuring are essentially complete. Computer analysis of the events is in progress.

¹Leroy T. Kerth and Abraham Pais, On the Gentle Art of Hunting Bumps in the Pion-Hyperon System, UCRL-9706, May 1961.

Lifetime of the Lambda

Sun Yui Fung

A sample of 3447 lambdas was obtained from the interaction of 1.11 ± 0.03 -BeV/c K mesons in the 30-inch propane bubble chamber at the Bevatron. The Barlett S function was plotted, and the mean life of the lambda was found to be $2.52 \pm 0.08 \times 10^{-10}$ sec. Various criteria in lambda momenta, actual decay lengths, and fiducial volumes were applied, and the variations in the results were consistent with the above errors.

Polarization of the Neutron from Σ Decay

Robert W. Birge

Recoil protons from the neutrons in Σ decay have been found and measured. To date only 20% of the expected number fit the requirements of the multivertex constraint program. We are re-evaluating the number of events expected on the basis of the experimental distributions of the neutrons, and are checking the uncertainties in the kinematic fits made by the computer. Progress has been slow because of unexpected problems in the programs.

The Muonic Decay Rate of the Lambda Hyperon

A. Kernan, Wilson M. Powell, and Carl Sandler

We are attempting to estimate the muonic decay rate of the lambda hyperon, using a sample of 15×10^4 visible lambda decays recorded in the 30-inch propane bubble chamber. The lambdas were produced by stopping K^- mesons in a mixture of 55% propane and 45% Freon by volume.

The branching ratio for beta decay of the lambda has been estimated at $(1.0 \pm 0.3) \times 10^{-3}$ (see report above on beta decay of hyperons, p. 91). If the ratio for the two leptonic modes of decay $\frac{\Lambda \rightarrow N + \mu + \nu}{\Lambda \rightarrow N + e + \nu}$ is proportional to their phase-space ratio, about 90 muonic decays are expected in our sample.

There are approximately 10^3 lambda decays in which the meson track terminates with a $\mu^- \rightarrow e^- + 2\nu$ decay; these are predominantly nonleptonic decays in which the pion decays in flight. We are applying various kinematical criteria to separate out any muonic decays that may be present.

DATA REDUCTION

Robert W. Birge and Paul W. Weber

A. SystemScanning: Gary Griffin, Larry Oswald, F. Swartz

To allow faster film handling, one-third of the two-view scanning projectors in the group have been improved by: (a) designing a tilting top for film-loading accessibility, (b) modifying the film drive to a positive motor-driven system, and (c) installing an automatic frame-centering device. Film scratching has virtually been eliminated by the design of a delayed film gate. Also, an improved projection system, which closely parallels chamber optics, enables scanners to utilize spatial relationships within the chamber.

In the near future, 35-mm four-view film will be scanned on modified two-view projectors.

To accommodate the new three-view format of the heavy-liquid bubble chamber, a scanning projector incorporating the advanced two-view projector features is being designed and is near completion. The scanner will handle both 70-mm and 46-mm film.

Measuring: Norman Andersen, B. Antuna

The Franckenstein measuring projector is processing three-view 46-mm as well as three-view 70-mm film. Both a refined detecting head system and an external magnifying system have improved setting accuracy.

The two digitized microscopes and the Franckenstein have been constantly checked with a straight-line program that has shown an abnormally high error rate on one microscope and the Franckenstein. This condition will be remedied with the addition of advanced datex Encoders. Transistorized translators have been suggested to prolong encoder life, and are under serious consideration. It is hoped that the incorporation of these improvements will reduce the event-rejection rate from 25% to 10%, thus increasing the measuring capacity.

B. Operation

With a total effort of 14 (full-time equivalent) Visual Measurement personnel, the following data reduction was accomplished in the past 6 months.

Scanning

Expt. No.	Bubble chamber	Beam	No. of frames
16	30-inch propane	1.15-BeV/c K^-	20,000
23	30-inch propane	4.50-MeV/c K^-	88,250
24	72-inch hydrogen	1.17-BeV/c π^-	620
25	72-inch hydrogen	3.31-BeV/c π^-	3,610
26	72-inch hydrogen	1.17-BeV/c π^-	575
27	72-inch hydrogen	1.53-BeV/c K^-	15,800
Total			128,855

Measuring

The following is a summary of the measuring activity during this half year. [Equipment code: D = Franckenstein measuring projector (MP-IC); C and E = digitizing microscopes]

Expt. No.	Origins measured	Remeasures	Equipment			Part of effort (%)
			C	D	E	
16	4268	1343	2807	70	2734	23.6
18	16	0	16	0	0	0.1
19	96	102	139	59	0	0.8
20	2031	541	1373	0	1199	10.8
21	11	339	0	0	350	1.5
22	0	112	0	0	112	0.5
23	9944	1990	3723	1248	6963	50.1
24	78	75	24	129	0	0.5
25	1721	375	0	2096	0	8.8
26	324	0	0	324	0	1.4
27	446	0	0	446	0	1.9
Total	18935	4877	8082	4372	11358	100.0

<u>Equipment</u>	<u>Measuring hours</u>	<u>No. of vertices</u>	<u>Vertices Meas. hours</u>	<u>Meas. hours 4032 hours</u>
C	1338.9	8082	6.04	34.4%
D	1375.7	4372	3.18	34.1%
E	1685.7	11358	6.74	41.8%
Total	4400.3	23812	5.41	36.4%

Note: Further data reduction is performed by using the FOG-CLOUDY-FAIR data-analysis system.

PHYSICS RESEARCH

Emilio Segrè and Owen Chamberlain in charge

POLARIZATION OF THE NEUTRON
IN $\pi^- + p$ CHARGE-EXCHANGE SCATTERING

Norman E. Booth, Robert J. Esterling, Roger E. Hill,
David A. Jenkins, Norman H. Lipman, Hugo R. Rugge, and Olav T. Vik

During this reporting period, a measurement was made of the polarization of the neutron produced in the reaction $\pi^- + p \rightarrow \pi^0 + n$ at an incident pion energy of 310 MeV. This measurement followed a preliminary experiment conducted during the preceding reporting period.¹ The second experiment, as the first, utilized a pion beam produced at the 184-inch synchrocyclotron impinging on a liquid hydrogen target, but used an improved version of the liquid helium analyzer. The principal improvements of the analyzer were the addition of a second photomultiplier tube viewing the analyzing volume, and the modification of the apparatus to allow for rotation about the hydrogen target.

Data were taken at a barycentric scattering angle of 30° on both sides of the incident pion beam. Some additional data were taken at a barycentric scattering angle of 45° . Analysis of these data is now in progress.

Our early findings indicate that the measurement was probably successful in that the data display the expected behavior; as one example, the sign of the left-right asymmetry reverses in going from one side of the pion beam to the other. The final polarization numbers await the completion of the analysis of the experimental data and a detailed calculation of the effective analyzing power of the system.

PION BETA DECAY

Robert Bacastow, Tom Elioff, Rudolf Larsen,
Clyde Wiegand, and Thomas Ypsilantis

Experimental work on the branching ratio for the decay process $\pi^+ \rightarrow \pi^0 + e^+ + \nu$ was continued at the 184-inch cyclotron. A report on the work has been submitted to Physical Review Letters.² A total of 5.6×10^{10} π^+ mesons were stopped in a counter system whose efficiency in detecting the rare decay mode was 0.77%. Six events were found leading to a branching ratio of 1.4×10^{-8} .

Experimental effort is being continued on pion decay processes. We will try to measure the branching ratio for

$$\pi^+ \rightarrow e^+ + \nu + \gamma$$

and try to improve our results on the beta decay.

¹ Physics Division Semiannual Report, UCRL-10349, May 1962, p. 68.

² Robert Bacastow, Tom Elioff, Rudolf Larsen, Clyde Wiegand, and Thomas Ypsilantis, Measurement of the Branching Ratio for Pion Beta Decay (UCRL-10486, October 1962).

DETECTION EFFICIENCY OF PLASTIC SCINTILLATOR
FOR NEUTRON ENERGIES 4 TO 76 MeV

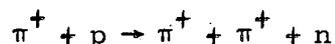
Clyde E. Wiegand, Tom Elioff, William B. Johnson,
Leonard B. Auerbach, Joseph Lach, and Thomas Ypsilantis

In connection with the instrumentation for our study of pion-pion interactions, we measured the neutron-detecting efficiency of plastic scintillation material. A description of the work has been published.³ We report the results in the accompanying figure (Fig. 1).

STUDY OF PION-PION INTERACTIONS FROM PION PRODUCTION BY PIONS

Leonard B. Auerbach, Tom Elioff, William B. Johnson,
Joseph Lach, Clyde E. Wiegand, and Thomas Ypsilantis

Analysis of our data on the reactions



at incident pion momentum 1.75 BeV/c has been completed and reported.⁴

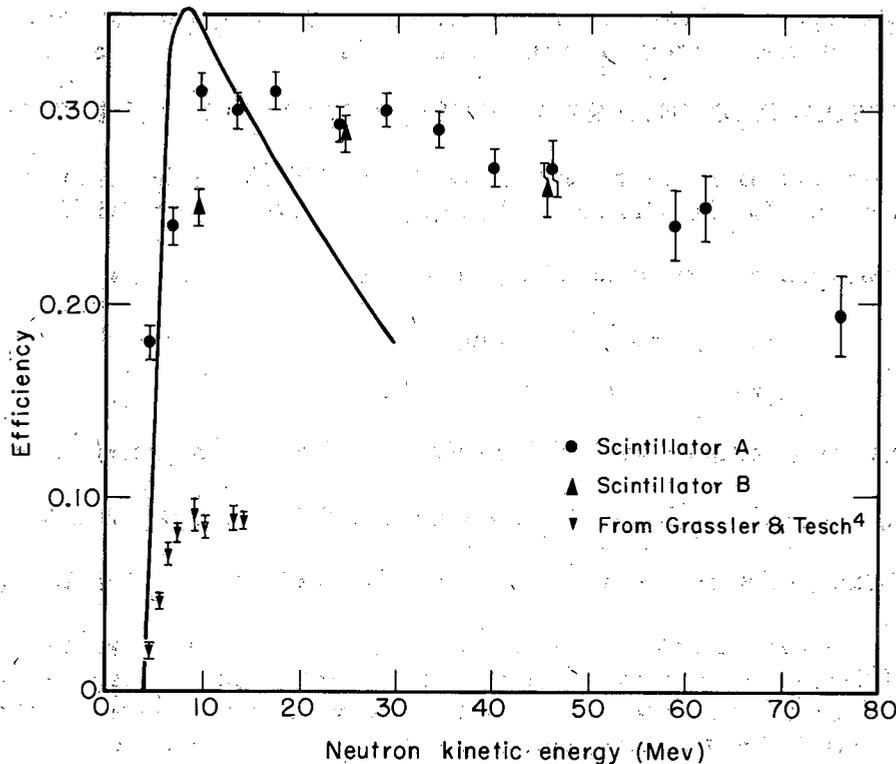
TARGET CONTAINING POLARIZED HYDROGEN

Owen Chamberlain, Helmut Dost, Claude Schultz, and Gilbert Shapiro

Following mainly techniques suggested by the work of Professor C. D. Jeffries, we have successfully obtained significant polarization of the hydrogen nuclei in the water of crystallization of lanthanum magnesium double nitrate. The technique follows closely the method described in a recent article by T. J. Schmugge and C. D. Jeffries [Phys. Rev. Letters 9, 268 (1962)]. The total sample weight was 20 grams, of which only 0.6 g was hydrogen; we had substituted neodymium (even isotopes) for 1% of lanthanum. We have achieved hydrogen polarization of 20% in a field of 9000 gauss, using microwaves of 35 kMc/sec. The temperature was 1.5°K. The polarized target will probably be used initially for studies of pion-proton scattering near the energy of the 3, 3 resonance and of proton-proton scattering near 700 MeV.

³C. Wiegand, T. Elioff, W. B. Johnson, L. B. Auerbach, J. Lach, and T. Ypsilantis, Rev. Sci. Instr. 33, 526 (1962).

⁴L. B. Auerbach, T. Elioff, W. B. Johnson, J. Lach, C. E. Wiegand, and T. Ypsilantis, Phys. Rev. Letters 9, 173 (1962).



MU-25526

Fig. 1. Counting efficiency versus neutron energy for two sizes of detectors, both 15 cm thick. Counter A was 20X60 cm, B was 20X20 cm. The curve shown is the calculated efficiency considering only single n-p collisions.

π^+ -p ELASTIC SCATTERING AT 250 MeV

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

The π^+ -p elastic differential cross section at 250 MeV was measured by observing the angular distribution of scattered pions at ten selected angles. Protons scattered at these angles were discriminated against by means of a water Cerenkov counter. The experimental data are not yet fully reduced.

It is hoped that in conjunction with the results of a forthcoming pion-scattering experiment with a polarized proton target a unique set of phase shifts can be reported.

PHYSICS RESEARCH

George H. Trilling and Gerson Goldhaber in charge

STUDY OF K^+ DECAYS

John L. Brown, John A. Kadyk, George H. Trilling, and
Remy T. Van de Walle

(in collaboration with Byron P. Roe and Daniel Sinclair
of the University of Michigan)

Studies of the $K_{e3}^+ \rightarrow e^+ + \pi^0 + \nu$ and $K_{\mu 3}^+ \rightarrow \mu^+ + \pi^0 + \nu$ decays obtained in a xenon bubble chamber have been continued. Detailed study of energy spectra and angular correlations has led to results in satisfactory agreement with present theories. This work has been published.¹

STUDIES OF K^0 DECAYS

John L. Brown, John A. Kadyk, and George H. Trilling
(in collaboration with Byron P. Roe, Daniel Sinclair, and J. Vander Velde
of the University of Michigan)

The analysis of the data used in obtaining the branching ratio

$$B_K = \frac{K_1^0 \rightarrow 2\pi^0}{K_1^0 \rightarrow 2\pi^0 + K_1^0 \rightarrow \pi^+\pi^-}$$

has been completed, and we have as our final result $B_K = 0.335 \pm 0.014$, in excellent agreement with the $T = 1/2$ rule prediction of 0.337 (including phase-space corrections). This work is being published.²

HIGH-FIELD BUBBLE CHAMBER

John L. Brown, John A. Kadyk, and George H. Trilling

Design studies for a large 40-kilogauss magnet using superconducting coils are being carried out in collaboration with the superconducting-coil group. Optimization of the design awaits the results of small-coil tests being carried out under the auspices of that group.

¹ John L. Brown, John A. Kadyk, George H. Trilling, Remy T. Van de Walle, Byron P. Roe, and Daniel Sinclair, Phys. Rev. Letters 8, 450 (1962); also John L. Brown, John A. Kadyk, George H. Trilling, Remy T. Van de Walle, Byron P. Roe, and Daniel Sinclair, Experimental Study of the $K_{\mu 3}^+$ and K_{e3}^+ Decay Modes of the K^+ Meson, UCRL-10205, Aug. 1962.

² John L. Brown, John A. Kadyk, George H. Trilling, Byron P. Roe, Daniel Sinclair, and John C. Van der Velde, New Determination of the K_1 Branching Ratio (UCRL-10539, Nov. 1962), Phys. Rev. (to be published).

K^+ -p INTERACTION FROM 140 TO 642 MeV/c*

Gerson Goldhaber, Sulamith Goldhaber, Wonyong Lee,[†]

Thomas A. O'Halloran, and Theodore F. Stubbs[‡]

(in collaboration with William Chinowsky of the Segrè Group and G. M. Pjerrou, Donald M. Stork, and Harold K. Ticho, Department of Physics, University of California, Los Angeles, California)

A detailed investigation of the energy dependence of the K^+ -proton scattering cross section at low momenta has been carried out in the 15-inch bubble chamber. In the region from 140 to 642 MeV/c the nuclear cross section varies little with energy. The cross sections are distinctly lower than values quoted earlier.¹ The momentum dependence of the phase shifts below 300 MeV/c can only be interpreted as s-wave scattering, and does not admit isotropic p-wave solutions such as were obtained as possible ambiguities at 810 MeV/c². The isotropy in the differential cross sections and the constructive interference with Coulomb scattering at each of the momenta show that the repulsive s-wave character of the K^+ -p $T = 1$ state persists throughout this region. The experimental data and the s-wave fit to it are summarized below.

Experimental results, $T = 1$ S-wave fit

$\frac{P_K}{c}$ (MeV)	Cross section		δ_L (degrees)
	Nuclear + Coulomb for $\cos\theta_{c.m.} = 0.85$ (mb)	Nuclear (mb)	
140±20	14.9±2.5	9.2±2.1	- 7.2±0.8
175±15	16.0±2.4	12.5±2.2	-10.4±0.9
205±15	13.7±1.8	11.5±1.7	-11.7±0.9
235±15	12.7±1.6	11.2±1.6	-13.2±0.9
265±15	11.0±1.6	10.0±1.6	-14.0±1.1
355±25	11.9±1.2	11.7±1.2	-20.0±1.1
520±15	11.9±1.2	12.2±1.3	-29.4±1.7
642± 7	11.9±0.8	12.4±0.9	-36.2±1.4

* Reported in Phys. Rev. Letters 9, 3 (1962).

[†] Now at the Nevis Laboratories of Columbia University.

[‡] Now at Lawrence Radiation Laboratory Livermore.

¹ T. F. Kycia, L. T. Kerth, and R. G. Baender, Phys. Rev. 118, 553 (1960).

² T. F. Stubbs, H. Bradner, W. Chinowsky, G. Goldhaber, S. Goldhaber, W. Slater, D. M. Stork, and H. K. Ticho, Phys. Rev. Letters 7, No. 5, 188 (1961).

K^+ -p INTERACTIONS AT 1.96 BeV/c

Gerson Goldhaber, Sulamith Goldhaber, Wonyong Lee,
Thomas A. O'Halloran, and Bertram M. Schwarzschild
(in collaboration with William Chinowsky of the Segrè Group)

An experiment of K^+ -meson interaction with hydrogen was performed in the 20-inch bubble chamber exposed in the Yale-Brookhaven separated K^+ beam at the AGS.

The study of the inelastic channels giving rise to three and four particles respectively in the final state permitted us

- (a) to determine the spin on the K^* to be $J = 1$ (the details of this study have been published¹),
- (b) to study the one-pion-exchange model in the reaction $K^* + N^*$,
- (c) to study the K^* spin alignment in the reaction $K^+ + p \rightarrow K^* + p$.

MESON EXCHANGE IN THE REACTION $K^+ + p \rightarrow K^* + N^*$

The reaction $K^+ + p \rightarrow K + \pi + N + \pi$ behaves essentially like a two-particle reaction giving a K^* ($I = 1/2$) and an N_{33}^* ($I = 3/2$). The cross sections for the various charged modes measured to date are:

$$\sigma(K^+ \pi^- p \pi^+) = 1.9 \pm 0.2 \text{ mb}, \quad (1)$$

$$\sigma(K^0 \pi^0 p \pi^+) = 1.4 \pm 0.3 \text{ mb}, \quad (2)$$

$$\sigma(K^0 \pi^+ n \pi^+) = 0.35 \pm 0.1 \text{ mb}. \quad (3)$$

In Reaction (1) we can define as the "resonance regions" $840 \leq M_{K^+\pi^-} \leq 940$ MeV and $1130 \leq M_{p\pi^+} \leq 1300$ MeV. The experimental production is as follows.

Products	Production (%)
$K^{*0} + N^{*++}$	64
$K^+ + \pi^- + N^{*++}$	25
$K^{*0} + p + \pi^+$	5
$K^+ + \pi^- + p + \pi^+$ (nonresonant)	6

These percentages are in good agreement with calculations based on the "one-pion-exchange" model.² The latter also gives quantitative agreement with the distribution in $M_{K^+\pi^-}$, $M_{p\pi^+}$, and the K^* -production angular distribution, which is observed to be strongly forward peaked. Furthermore, the model can explain the strong K^* spin alignment we reported earlier.¹

¹Chinowsky, Goldhaber, Goldhaber, Lee, and O'Halloran, Phys. Rev. Letters 9, 330 (1962).

²Salzman and Salzman, Phys. Rev. 120, 599 (1960).

K^* SPIN ALIGNMENT IN THE REACTION $K^+ + p \rightarrow K^* + p$

The reaction $K^+ + p \rightarrow K^0 + \pi^+ + p$ proceeds essentially through two distinct channels, viz: (1) $K^{*+} + p$ and (2) $K^0 + N_{33}^{*+}$, together with an interference region between them. The cross section for both channels is 4.3 ± 0.3 mb, based on 288 observed events with the K_1^0 charged decay mode and 268 τ decays. In channel 1 the K^* production is strongly forward peaked, while the N^* production in channel 2 is strongly backward peaked. It is noteworthy that the N^* production (channel 2) cannot proceed via a single pion exchange.

DATA HANDLING

Howard S. White in charge

The Data Handling Group began operation on July 1, 1962, having previously operated as a section of the Powell Group. This report covers the entire six-month period from April 1 through October 31, 1962.

DEVELOPMENT

Flying-Spot Digitizer System

Howard S. White and Jack V. Franck

Fabrication and debugging of mechanical and electronics hardware for the Flying-Spot Digitizer (FSD) continued during the period of this report. The final spot-generating slit disc was installed in October. Further work remains to be done on the film-transport mechanism. The sheet metal covering and the operator's console for the machine also remain to be completed. With the exception of some minor items, all other hardware is now completed and is mostly operational.

The first event to be measured with the Flying-Spot Digitizer System was described at the CERN Instrumentation Conference in July.¹ This event, a Σ production and decay, was measured and the data were reduced by procedures intended for the final production programs. The results were compared with several Franckenstein measurements made on MPIC and gave evidence of being at least as accurate as the best of several measurements obtained with the Franckenstein.

By October 1 the hardware had reached a stage of development that made possible digitizings of several pictures taken from the K^- run at the 72-inch hydrogen chamber. The "roads" made on the scanning table were fitted to tracks in these pictures and final debugging of production programs was made possible. By the end of October a number of tracks had been followed and filtered. Five events were satisfactorily reduced by use of the FOG-CLOUDY programs.

A delay of several weeks was caused by a difficulty of overlaying roads generated from the scanning table digitizings upon the FSD measurements. This unexpected difficulty in operation was caused by the discovery that for all existing Berkeley film, only one external fiducial mark could be used to relate the coordinates measured on the digitized scan table to those measured on the FSD. Although three other fiducials are contained within the chamber, focus and exposure on existing film were not held within sufficient tolerances to make the other fiducials always usable. This imposed the very stringent requirement that film must be mechanically constrained so as to be repositioned to tolerances of less than 1 mil at either end of the film frame. The requirement necessitated some modification of the film-transport mechanism, but was the only means by which the measurements could be made of the existing Berkeley film. The problem has now been solved successfully by the mechanical positioning of film.

¹ Proceedings of the International Conference on Instrumentation for High Energy Physics, CERN (Nuclear Instruments and Methods, North-Holland Publishing Company, 1962).

The design of the SPVB scanning projector for the Flying-Spot Digitizer was completed, and one such device was fabricated and put into operation. Preparations were begun for fabrication of three additional identical machines. These scanning projectors will share a common magnetic-tape recording unit, which will be used to accumulate scanning information for later use by the computer in controlling measurement with the FSD.

The design of the SPV is based upon the design of the earlier SPIV, but several improvements have been made to this design. These include provision for 70-, 46-, and 35-mm film as well as for the format used by Brookhaven and CERN chambers in addition to that used by the Berkeley chambers. Also the design has been changed to make film loading easier than on the previous model projector. Scanning for the Flying-Spot Digitizer requires that points be digitized to an accuracy of ± 2 track widths (approximately ± 2 mils on the film) over the image of the bubble chamber. This has required only an improvement of the optical quality of the mirrors over that in the SPIV projector. The required accuracy has been satisfactorily achieved.

It is desirable that the scanning process go rapidly so that the minimum number of scanning tables can be used to provide control information for the FSD. Therefore, correlation of identification information has been made as automatic as possible, and we observe that a typical event is measured by a trained scanner without previous experience on this machine in less than 3 minutes. This time agrees well with the predictions used in estimating the capacity of the Flying-Spot Digitizer system, and some improvement is expected as the scanner gets more experience with this equipment.

With successful operation of the scanning table demonstrated, we have begun fabrication of three additional machines.

Several computer programs were written and made operational during this period. Two are required for the operation of the Flying-Spot Digitizer system; the other programs are used as tools in debugging and maintaining the system. The program that sorts and edits scan table measurements into the sequence of pictures found on a roll was completed in June and has been tested with the data obtained on the FSD scan table. This program is required to separate the interleaved data from several scan tables operating with a common tape transport. It will handle film in the Berkeley and Brookhaven formats and is capable of dealing at one time with data from several different experiments.

The main Flying-Spot Digitizer program, HAZE, has progressed in step with the hardware developments and has been used in debugging the hardware. Gating and filtering of data obtained with the FSD has been done successfully and one event was processed in time to present at the CERN Instrumentation Conference in July.¹ Severe difficulties have been encountered because of the difficulty of finding fiducials in existing film and because only one fiducial can be regularly found. A new more sophisticated fiducial search has been written and is being debugged; it is hoped that with it at least one fiducial can be found in each view.

Two display programs utilizing the 7090 CRT have been written and are in use. One of these displays a specified area of the film digitized by the FSD at various magnifications, enabling one to closely examine the digitizings

of any part of a picture. The other CRT program displays the roads produced by the HAZE program together with the gated points within them to make possible evaluation of different techniques for filtering noise and other tracks from the track in question.

Equipment Fabrication

Two Franckenstein measuring projectors, MPIE and MPIF, are being constructed for use by the Trilling-Goldhaber Group and the Segrè Group respectively. These measuring devices are similar to those now in use at the Laboratory but will also be capable of measuring film in non-Berkeley formats as well as film ranging up to 70 mm in width. Provision will be made on MPIE for installation of hardware by which ionization can be measured by use of bubble-counting techniques. This measurement will be made concurrently with the measurement of track position. Completion of these measuring projectors is scheduled for Spring of 1963.

Two SCAMP measuring projectors are being fabricated for use by the Lofgren Group in measuring spark chamber pictures. These are adapted from the prototype SCAMP built by members of that group. Completion is scheduled for Spring 1963.

Five SPVA scanning projectors are being fabricated. These machines are identical in mechanical and optical design to the FSD scanning projector now designated as SPVB, but do not include electronics nor the digitizer necessary for FSD use. The mirrors will be selected plate, rather than specially lapped, glass, since the optical requirements for these projectors are not as stringent as for FSD use. SPVA scanning projectors will, however, incorporate the improvements previously described allowing the use of films from various other installations in addition to those produced at Berkeley. Completion is scheduled for Spring 1963.

FOG-CLOUDY-FAIR Computer Program

Howard S. White and Dennis Hall

Modification of the FOG program to operate in a multiprogrammed manner in conjunction with the FSD programs is nearly complete. The program now runs independently from the HAZE program, but in the locations and with the procedure it will use while time-sharing with HAZE. Since debugging can be done more rapidly with these programs operating independently, we have not yet combined them, although provision has been made in the present use for meeting demands caused by their concurrent operation.

A merging program for the FSD version of FOG output was written and debugged. This program allows for several short libraries generated by FSD runs on successive days to be collected onto a single library for the entire experiment.

The curve-fitting sections of the FOG program were prepared for reassembly, with modifications making provisions for as many as five kinks per track as well as a more flexible provision for calculating magnetic fields in different chambers. These programs are now reducing events from the 30-inch propane, and the 72-inch and 15-inch hydrogen chambers at Berkeley,

as well as the 20-inch hydrogen chamber at Brookhaven and the 1-meter propane chamber at École Polytechnique.

The abstracting portion of the CLOUDY system (Program 208) was plagued by an intermittent 7090 computer failure. Several man-months of effort were expended in establishing to IBM's satisfaction that the program was not at fault, but that core memory was failing. In addition to this effort expended upon maintenance of operations, there was work applied to greatly extending program logic capability for dealing with several levels of mass permutations in Program 208. It is now possible to allow the level entries to have a generalized OPS (particle-identification) code, so that one level entry represents an entire class of reactions. A level represents a plateau of reaction probability, so that attainment of satisfactory kinematic fits within a more probable level can be made to preclude computations in less probable levels, so as to limit expenditure of computing time. The ability to handle FSD output was added to all CLOUDY programs.

The kinematic section (Program 209) of the CLOUDY system was reassembled with many added improvements. The subroutine that calculates the Σ momentum based on the momentum and angle of the π was improved to find the "closest" real solution in the case in which two imaginary solutions were obtained. Multivertex constraints on charged connecting vertices were also put into useful physics production. Finally, a new form for calculating the range-momentum function was installed in the CLOUDY system for use with propane-freon mixtures.

The level-defining ability of the FAIR system was extended in a re-assembly of the abstraction program (304). "Level" is a term used to characterize a group of events chosen as representing an arbitrary set of numerical or logical selection criteria. This change allows "global levels" to be defined over any subset of mass hypotheses of a given event. Planning of the FAIR compiler was continued during this period. As a temporary solution to the need for a FAIR compiler, the ability to generate a FORTRAN input tape was added to Program 305. This allows a physicist to perform further numerical calculations on his data, using a FORTRAN program of his own design. Work was begun on Program 305 to provide the ability to request detailed pages of FAIR output for specific events satisfying given levels. This ability will be especially useful for examining those events that fail to fall into any expected kinematical category.

A KICK-to-FAIR conversion program, Program 307, was written and debugged. This allows physicists having KICK data to use the FAIR system for analysis of their events.

Automatic Scanning Program

Howard S. White and Charles Dickens

The success of the FSD automatic measurement program has given encouragement concerning the possibility of automatically scanning as well as automatically measuring bubble chamber film. Programs written at Brookhaven by Pasta, Marr, and Rabinowitz were acquired and made

operational at Berkeley.² It was found that these programs as written were not especially suitable for following tracks for the Berkeley 72-inch hydrogen chamber, and therefore some modification of these programs was necessary in order to allow them to operate here. Other prototype programs have been written at Berkeley, using different strategy for track following, and from all these it is believed an overall strategy can be generated that will allow automatic scanning of pictures. Because these are prototype programs, a skeleton control program has been written which initializes the various parts that test different strategies, and then operates an output display program for visual evaluation of the several strategies. A total of four programs has been written in this manner. At present, beam tracks have been followed for up to 3/4 of the length of the 72-inch chamber. Since this chamber is the largest one in which automatic track following has been attempted, these constitute the following of more track length than any program has achieved elsewhere. Work is continuing upon the improvement of strategy for following tracks in both hydrogen and propane chambers.

A proposed procedure for applying scanning criteria to the measurements of data contained in bubble chamber film abstracted onto magnetic tape was described at the CERN Instrumentation Conference.³ This procedure would divide the process into two parts: (a) track-recognition, measurement, and abstraction phase, in which each stereoscopic view of the film would be searched for all track segments and which would yield precision measurements on magnetic tape, (b) a subsequent scanning phase, in which the magnetic tape abstract would be examined in comparison with selection criteria defining the types of events desired, and which would yield an output tape, suitable for input to FOG, containing those events meeting the selection criteria.

OPERATIONS

FOG-CLOUDY-FAIR

During the period May 1, 1962 through October 31, 1962, the FOG program processed 44,182 origins from four different bubble chambers.

Approximately 17,000 of these origins were re-runs. That is, an improvement of such significance as to warrant reprocessing for this class of events was made to the FOG program. A summary of the current experiments is shown in Table I.

Identification of particle and charge was generated automatically by Program 119 for 15,320 of these events. This program allows events to be automatically tested against a predefined series of event-type hypotheses, and specifies that the particle identification of the event is of the requested type. The remainder of the events were assigned particle and charge

²J. Pasta, R. Marr, and G. Rabinowitz (Brookhaven National Laboratory), private communication.

³Howard S. White, An Automatic Scanning System for Bubble Chambers, CERN International Conference on Instrumentation for High Energy Physics (to be distributed as CERN Internal Note).

Table I. Summary of bubble chamber events processed by FOG program.

Experiment	Beam momentum (BeV/c)	Particle	Bubble chamber	Vertices computed
16	1.15	K^-	30-inch propane	4467
18	0.5	θ_2	30-inch propane	8
19	3.30	π^-	72-inch hydrogen	8670
20	0.75	K^+	30-inch propane	2476
21	0.75	π^+	15-inch hydrogen	239
22	0.75	π^+	15-inch hydrogen	78
23	0.50	K^-	30-inch freon	23832
24	1.17	π^-	72-inch hydrogen	154
25	3.30	π^-	72-inch hydrogen	3152
98	17.0	K^-	100-cm freon	1106
				44,182

identification by a manual process. This option allows a greater flexibility in identifying individual events, and allows the scanner to positively specify mass identifications of which he is certain from visual scanning.

A total of 26,279 new events was processed through the CLOUDY system of programs to be used in 22 different experiments. A summary of these experiments is shown in Table II.

The FAIR system of programs abstracted 48,337 chains from 19 experiments, contained on separate CLOUDY libraries. The FAIR programs abstract from the CLOUDY library only the information that is of interest to the experimenter. It is then economically feasible to perform many different statistical analyses as well as to calculate additional quantities from the abstracted parameters. These abstracted libraries were passed through the computer a total of 85 times, each pass taking only a few minutes but producing a new statistical summary of the data based upon information gained from previous passes.

Table II. Summary of events processed by CLOUDY program.

<u>Experiment</u>	<u>Events</u>
AW01 - AW05 (Werbrouck)	2317
CW01 (Whatley)	408
HW03 (Fretter)	236
HW04 (Ely)	572
JG01 - 02 (Gaidos)	1171
PN01 - 02 (Newcomb)	386
RB01 - 02 (Birge)	87
TS01 - 02 (Schuman)	3743
WP08 (Powell)	7291
WP13 (Kernan)	715
WP15 (Ely)	898
WP16 (Powell)	8
WP17 (Powell)	211
ZG04 (Guiragossian)	8236
	<u>26,279</u>

ACCELERATOR OPERATION AND DEVELOPMENT

BEVATRON

Edward J. Lofgren in charge

The report for November 1961 through January 1962 has been issued as "Bevatron Operation and Development. XXXII," UCRL-10347, December 1962.

Reports XXXIII, XXXIV, and XXXV (for February through April, May through July, and August through October 1962) have not yet been prepared.

184-INCH CYCLOTRON

Robert L. Thornton in charge

Reported by James T. Vale

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

88-INCH CYCLOTRON

Elmer L. Kelly in charge

In this six-month period, the 88-inch cyclotron has been brought into productive operation; an external beam of half-energy α 's of exceedingly good quality has been delivered into an experimental cave and used for scattering experiments.

A few isotope-production runs have been made.

With the internal beam limited to about $20 \mu\text{A}$, we typically get $5 \mu\text{A}$ of external beam that can easily be focused on an external isotope-production target. For scattering experiments, the beam is bent 57° by the switching magnet and collimated by a slit 0.080 in. wide by 0.5 in. high. Through this slit one gets from 0.25 to $0.40 \mu\text{A}$. This is sufficient beam for essentially all the nuclear reaction experiments, and far too much for coincidence counting experiments (in which something like $1 \text{ m}\mu\text{A}$ is all one can use, anyway).

We have completed a study of the elastic and inelastic scattering of 65-MeV helium ions from C^{12} , N^{14} , and O^{16} . Using the switching magnet as a beam monochromator, and detecting scattered particles with a lithium-drifted silicon diode, we have obtained a resolution in energy of 140 keV. The main source of energy spread is probably still the beam itself.

We expect to achieve, within the next six months, extended beams of higher energies and of other particles--alphas, protons, He^3 , and probably deuterons.

HEAVY-ION LINEAR ACCELERATOR

Albert Ghiorso in charge

Reported by Edward L. Hubbard

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

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