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PHYSICS DIVISION SEMIANNUAL REPORT

November 1961 through April 1962

Berkeley, California

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GENERAL PHYSICS RESEARCH

PHYSICS RESEARCH

Luis W. Alvarez in charge

RESEARCH WITH BUBBLE CHAMBERS

The K72 Experiment (72-Inch Chamber)

General Information

The group continues to devote a large fraction of its physics research activity to the operation of the separated high-energy K^- beam and the analysis of the resulting data.

Approximately three-quarters of the Bevatron time scheduled for this experiment has been used. The beam design has been discussed previously. The operation of the Bevatron, K72 beam and 72-inch bubble chamber has been highly efficient. A total of approximately 11,000 MBE's (1-mb-equivalent events) has been obtained in some 500,000 pictures at several momenta over the range of 1.05 to 1.97 BeV/c. The pictures for the two higher momenta (1.83 and 1.97 BeV/c) are being analyzed by UCLA. This number of pictures has yielded approximately 500 Ξ^-, 50 Ξ^0, 55,000 Λ, 40,000 Σ, and 28,000 $\overline{K}^0$ decays associated with zero, two, or four-prong events. The first scanning of this film is about one-half finished. The measuring and analysis of the events in these pictures are approximately one-fourth complete. Analysis of all the Ξ, Λ, Σ, and $\overline{K}^0$ events is expected to take another full year to complete. Present results of the various experiments from the K72 complex are given below.

Study of Y_1^*, η, and ω in V Two-Prong Events

A systematic investigation of the "two-prong vee" final-state topology in $K^- + p$ reactions observed in the K72 run is proceeding as rapidly as possible. Ultimately, the analysis will include from 2000 to 10,000 such reactions at each of six K^- momenta from 1.22 to 1.73 BeV/c at approximately 100-MeV/c intervals. To date, about 3000 events at 1.22 BeV/c and 1000 events at 1.53 BeV/c have been analyzed. Those events in which the "vee" particle is a $\overline{K}^0$ meson are discussed later (see K^* below). The remaining vee

events (Λ particles) arise from $\Lambda\pi^+\pi^-$, $\Lambda\pi^+\pi^-\pi^0$, $\Sigma^0\pi^+\pi^-$ ($\Sigma^0 \rightarrow \Lambda + \gamma$), etc. The $\Lambda\pi^+\pi^-$ and $\Lambda\pi^+\pi^-\pi^0$ final states are often by-products of the primary reactions $Y_1^{*\pm}\pi^\mp$ and $\Lambda\eta$ (or $\Lambda\omega$, energy permitting) respectively, and presently constitute our most copious source of data on the Y_1^*, η (or χ), and ω resonances. Following is a summary of some of the more significant preliminary results.

The $\Lambda\pi^+\pi^-$ production may be accounted for by assuming that the reaction proceeds entirely through the Y_1^* channel with a cross section that decreases with increasing K^- momentum: 2.2±0.2 mb and 1.4±0.3 mb respectively at 1.22 and 1.53 BeV/c. The relative contribution from the I = 0 and I = 1 channels is changing with K^- momentum, as evidenced by the Y_1^{*+}/Y_1^{*-} ratio: 4/5 at 1.22 BeV/c and 5/4 at 1.53 BeV/c. Anisotropy in the Y_1^* decay angular distribution with respect to the production normal (favoring polar decays) is observed in 1370 Y_1^* events at 1.22 BeV/c, although the deviation from isotropy is about one standard deviation. This type of anisotropy at 1.11 BeV/c K^- momentum, in the 380 Y_1^* events of Ely et al.[1], constitutes the chief evidence suggesting that the Y_1^* spin is greater than 1/2. No significant polarization of the Λ has been observed to date.

The production of $\Lambda\pi^+\pi^-\pi^0$, on the other hand, is much more complicated. At 1.22 BeV/c there is evidence for production of $\Lambda\eta$ with a 55-μb cross section for the charged mode of decay, and for production of the 1520-MeV/c^2 Y_0^* with about a 30-μb cross section. The total $\Lambda\pi^+\pi^-\pi^0$ cross section is about 0.6 mb at 1.22 BeV/c. At 1.53 BeV/c the $\Lambda\pi^+\pi^-\pi^0$ final state is dominated by $\Lambda\omega$ production (about 90% of the cross section of 1.4 mb for $\Lambda\pi^+\pi^-\pi^0$), whereas the $\Lambda\eta$ cross section is still ≈ 50 μb. The η analysis is discussed below.

Production of η Mesons in $K^- + p$ Interactions at 1.2 BeV/c

In an attempt to establish the quantum numbers of the recently discovered η, a T = 0 meson of mass 550 MeV/c^2, interactions of the type

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

have been studied in the 72-inch hydrogen bubble chamber with incident K^- beams at 1.22 BeV/c and 1.55 BeV/c. Two topologies were examined: the "vee-two-prong" and the "vee-zero-prong", the first of these yielding events with Λ plus η decay into charged particles ($\pi^+\pi^-\pi^0$ or $\pi^+\pi^-\gamma$) and the second giving events with Λ plus η decay into neutrals (possibly $3\pi^0$, 2γ, or $\pi^0\gamma$). The mass and widths of the η, the cross sections for η production, the ratio of charged to neutral decays, the branching ratio into $\pi^+\pi^-\gamma$, and a limit on the branching ratio into $3\pi\gamma$ have been obtained. Dalitz plots and alignment studies of "charged η decays" have been made.

For the vee-two-prong events with fitted Λ decays that gave good kinematic fits to production of a Λ plus three pions ($\pi^+\pi^-\pi^0$) and poor fits to $\Sigma^0 2\pi$ and to $\Lambda 2\pi$, the effective mass of the three-pion system was calculated. Of the 2300 good Λ-decay events at 1.22 BeV/c, there were 320 that yielded good production fits to $\Lambda + \pi^+ + \pi^- + \pi^0$. The three-pion effective-mass plot for these events showed a peak at 548 MeV/c, with half-width of about 6 MeV (approximately equal to the mass resolution of the measuring system); this peak contained 44 events, of which about 10 were estimated to

[1] Robert P. Ely, Sun-yi Fung, George Gidal, Yu-Li Pan, Wilson M. Powell, and Howard S. White, Phys. Rev. Letters 7, 461 (1961).

be background. The 34 "charged η decay" events correspond to a production cross section of 55±15μb. A Dalitz plot of events in the η peak showed structure similar to that observed with fewer events in K^--proton interactions at 760 MeV/c. Of the 44 events in the peak, five or six could have been $\pi^+\pi^-\gamma$ decay of the η. No evidence was found for $3\pi\gamma$ decay, there being an upper limit of five or six such events.

In the same film at 1.22 BeV/c K^- momentum, about 1500 Λ zero-prong events were obtained. The missing neutral mass in the final state was calculated; and again a peak was found at 550 MeV/c^2, with an observed half-width of 10 MeV (slightly greater than the mass resolution of the system). The number of events in the resonant peak for "neutral η decay" was about three times the number of charged decays found in the same film.

The polarization of the lambdas produced in association with η mesons in both the charged and neutral decay events was found to be close to zero. Correlations in "charged η decay," both of the momentum of the π^0 and of the normal of the decay plane with the production normal, were found to be very small, and indicated that there was no alignment of η spin in the production process or that the spin of the η is zero.

At 1.53 BeV/c, some 300 Λ two-prong events and 400 Λ zero-prong events have been processed (only a portion of the available film). The cross section for η production in the "charged-decay" events has a value of about 50 μb at this momentum.

The neutral modes of η decay cannot yet be identified. From the appearance of the Dalitz plot and from the lack of alignment in decay, it seems likely that the η has spin-parity—G-parity of 0^{-+}; the only inconsistency with this assignment of quantum numbers is the low rate of radiative decays. The possibility of its being a 1^{--} meson is probably ruled out.

Study of K^* Production and Decay

At the incident momentum of 1.22 BeV/c, approximately 3000 K^- interactions producing V^0 two-prong events have been analyzed, of which about 500 were examples of the reaction

$$K^- + p \rightarrow \overline{K}^0 + \pi^- + p .$$

These were analyzed with the objective of obtaining the spin and parity of the K-π (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 greater than 1.

The analysis of the 1.22-BeV/c data is at present about 90% complete. It has been found that the majority (about 3/4) of the $\overline{K}^0 p\pi$ events proceed via the two-body mode

$$K^- + p \rightarrow K^{*-} + p$$

[2] Margaret Alston, Luis W. Alvarez, Philippe Eberhard, and others, Phys. Rev. Letters 6, 300 (1961).

followed by the decay

$$K^{*-} \rightarrow \bar{K}^0 + \pi^- .$$

The indications are that the width of the resonance is considerably higher than reported previously ($\Gamma \geq 45$ MeV) and that the central value lies at 890 MeV. The determination of these two parameters is hampered at this incident momentum by the fact that the resonance lies at a mass which 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, which would exclude spin 0. None of the three possible distributions showed any statistically significant deviations from isotropy.

Recently, the study of the same reaction was undertaken at the K^- incident momentum of 1.53 BeV/c. At present, the fraction of data processed is insufficient to draw any conclusions.

Analysis of Σ^+ and Σ^- Events

At 1.22 BeV/c the following reactions have been analyzed:

$$K^- + p \rightarrow \Sigma^{\pm} + \pi^{\mp} + \pi^0 , \qquad (1)$$

$$K^- + p \rightarrow \Sigma^{\pm} + \pi^{\mp} + \pi^- + \pi^+ , \qquad (2)$$

$$K^- + p \rightarrow \Sigma^0 + \pi^0 + \pi^- + \pi^+ . \qquad (3)$$

Some film at 1.53 BeV/c has also been analyzed to date. A search for various $\Sigma\pi$ resonances is being made (resonances have been observed previously at $\Sigma\pi$ masses of 1405 and 1520 MeV/c^2).

There are 473 $\Sigma^{\pm}\pi\pi^0$ events (Reaction (1)) in one-half the 1.22-BeV/c data (249 Σ^+ and 224 Σ^-). In the charged $\Sigma\pi$ combinations, little is seen at 1385 MeV/c^2 (the Y_1^* mass). Approximately 85 $(\Sigma\pi)^{\pm}$ pairs lie between 1340 and 1440 MeV/c^2, with some 12 of them above the phase-space prediction. Attributing all 85 to $Y_1^{*\pm} \rightarrow \Sigma^{\pm}\pi^0$ decay gives an upper limit of 7% for the branching ratio $(Y_1^* \rightarrow \Sigma\pi)/(Y_1^* \rightarrow \Lambda\pi + \Sigma\pi)$. A best estimate of 1% for this ratio is obtained from the 12 events above the phase-space calculation. The 1405- and 1520-MeV/c^2 $\Sigma\pi$ resonances are seen in the neutral $\Sigma\pi$ combinations with widths $\Gamma_{1405} = 50$ MeV/c^2 and $\Gamma_{1520} = 20$ MeV/c^2 respectively. The absence of a 1405-MeV/c^2 peak in the charged $\Sigma\pi$ suggests that the I spin is probably not unity. In order to ascertain if I = 0 is correct for this resonance, the final state (3) above was analyzed. This final state, $\Sigma^0\pi^0\pi^-\pi^+$, is difficult to separate from some other reactions: $\Lambda\pi^0\pi^-\pi^+$, $\Lambda 2\pi^0\pi^-\pi^+$, and $\Sigma^0 2\pi^0\pi^-\pi^+$. Various selection criteria were applied to isolate a reasonably pure sample of $\Sigma^0\pi^0\pi^-\pi^+$. The mass distribution of the missing $\Sigma^0\pi^0$ was obtained. Of the 159 events, 72 lie in the mass interval from 1340 to 1430 MeV/c^2, including some background. For an I = 0 1405-MeV/c^2 $\Sigma\pi$ resonance, 50 events are expected here (0 expected if resonance has I = 1 and 200 if I = 2). The assignment of I = 0 to the 1405-MeV/c^2-$\Sigma\pi$ resonance is therefore consistent with the data.

There were studied also 78 $\Sigma^-\pi^+\pi^-\pi^+$ and 81 $\Sigma^+\pi^-\pi^-\pi^+$ events (Reaction (3)). A definite peak in the mass distribution of the neutral $\Sigma\pi$ system is observed at 1405 MeV/c^2. The 1520-MeV/c^2 resonance does not appear. In the doubly charged $\Sigma\pi$ system ($\Sigma^-\pi^-$ or $\Sigma^+\pi^+$) no definite peak has yet been seen (although the phase space is limited in the present data), so that the I = 2 global symmetry resonance predicted (at a mass of approximately 1540 MeV/c^2) has yet to be found.

Analysis of Σ^+ and Σ^- events is continuing, especially in the search for the predicted I = 2 $\Sigma\pi$ resonance at the higher K^- momenta, where more phase space is available.

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

A sample of 33 Ξ^- at 1.22 BeV/c and 211 Ξ^- at 1.53 BeV/c from the reaction $K^- + p \rightarrow \Xi^- + K^+$ in the K72 film has been analyzed. The product of the decay parameters of the Ξ^-, α_{Ξ^-}, and of the Λ, α_Λ, is found for these 244 events to be

$$\alpha_\Lambda \alpha_{\Xi^-} = -0.24 \pm 0.11 .$$

Using the value $\alpha_\Lambda = -0.62$, we obtain

$$\alpha_{\Xi^-} = +0.39 \pm 0.20.$$

The production angular distribution of the Ξ^- in the c.m. of the K^--p system has a strong forward peak.

For Ξ^0 events, an additional constraint class has been added to the GUTS subroutine of the KICK program. The geometrical constraint that the incident K^-, the unseen Ξ^0, and the resultant Λ from the decay $\Xi^0 \rightarrow \Lambda + \pi^0$ are coplanar has been added to the kinematical two-vertex two-constraint class previously available in KICK. This feature will allow a cleaner separation of $K^- + p \rightarrow \Xi^0 + K^0$ events from the background of $\pi^- + p \rightarrow \Sigma^0(\Lambda) + K^0$ reactions.

Analyses of Ξ^- and Ξ^0 from the films for other momenta from the K72 experiment are in progress.

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

The 72-inch hydrogen bubble chamber was exposed to about 75,000 K^- mesons divided about equally between the incident momenta of 1.05± 3% and 1.11 ± 3% BeV/c. The purpose of the exposure is the study of the T = 0 resonance at 1815 MeV, discovered recently by the Lofgren group.

All the film has already been scanned and is now being measured. A systematic study is planned of all the interactions as a function of energy in the resonance region.

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

Asymmetry Parameters for Σ^+ and Σ^-

The asymmetry parameters for Σ^+_+, Σ^+_0, and Σ^- have been measured by using the polarization arising from the interference between the s-wave and the $d_{3/2}$ 1520- MeV/c^2 resonance. The results are in good agreement with the $|\Delta I| = 1/2$ rule.

An IBM 7090 program has been written to analyze the K^--p data in the vicinity of 400 MeV/c. The program uses s, p, and d waves and yields least-squares fits which are improvements of, and which are similar to, the hand analyses previously reported.

$\Sigma^- + p$ Interactions

Analysis of about 185 Σ^-+p interactions of the 1958 K^-+p exposure is being completed. Elastic scattering and charged-hyperon production from in-flight K^-p interactions of the 1960 exposure are being analyzed. It is expected that these additional data will substantially reduce the uncertainty of the present zero-effective-range parameters, and perhaps justify an attempt to fit the data to a more sophisticated theory of the type proposed by Ross and Shaw.[3] Measurements are being made on the Σ^-+p interactions available from the 1960 run to supplement the data we have from the 1958 exposure. One very unusual decay of the Σ^+ has been observed:

$$\Sigma^+ \rightarrow e^+ + e^- + \pi^+ + n .$$

A search for Σ electromagnetic decays without electron pairs is in progress.

Associated-Production Experiment (72-Inch Chamber)

Associated Production of ΛK^0 at ΣK Threshold

A sample of about 5,000 events is now completely "passing" (through the PANG and KICK kinematical analysis programs). Analysis into powers of cos θ in angular distributions and polarizations is in progress. Track-counting and determination of μ^- and e^- contamination, for determination of absolute cross sections, is complete. The μ^- contamination is about 5%, the e^- about 1/2%.

A second sample of about 5,000 events taken with a thinner bubble chamber window--to improve the momentum resolution (broadened by Landau straggling in the windows)--is now completely first-time-measured. When these were run through the PANG-KICK system about 70% passed. Second measurements are in progress.

Leptonic Decays of K^0_1 and K^0_2

The experiment on the first sample of about 5,000 associated-production events is completed. After many cutoffs have been imposed to eliminate biases, the sample consists of about 2700 Λ decays and 22 leptonic decays, distributed between t = 0 (at production) and 20.0×10^{-10} sec. We obtain two results, which are independent from an experimental point of view. First, by looking at leptonic decays beyond 4 K^0_1 mean lives we obtain the

[3] M. Ross and G. Shaw, Ann. Phys. 13, 147 (1961).

absolute decay rate of K_2^0 into leptons. We find

$$\text{Rate of } (K_2^0 \rightarrow e^{\pm} \text{ or } \mu^{\pm}) = (7.85 \pm 2.17) \times 10^6 \text{ sec}^{-1} .$$

This result is the first experimental determination of the absolute leptonic decay rate of K_2^0. (By combining previous experiments on K_2 lifetime by attenuation with distance and on K_2 branching ratios into observed decay modes, and by making assumptions as to the number of unobserved or rare modes such as $3\pi^0$ and $\pi\pi\gamma$, one can indirectly arrive at the leptonic decay rate.) Our result is only about 1/2 the value predicted by the $|\Delta\vec{I}| = 1/2$ rule. We obtain 13 events, whereas 26 ± 2 was predicted. We calculate odds of 1/170 for this to be a chance fluctuation.

Secondly, by comparing the number of leptonic decays at small times with that at large times, one obtains the ratio of leptonic decay rates of K_1^0 and K_2^0. This is a more difficult experiment than the first, since additional possible biases are present owing to the danger that a very small fraction of the very numerous "normal" K_1^0 decays may simulate leptonic decays. We believe that we have eliminated all these biases. (The most important ones are single Coulomb scattering of a decay pion from $K_1^0 \rightarrow \pi^+\pi^-$, and Dalitz decay of a π^0 from $K_1^0 \rightarrow 2\pi^0$.) Our result is that the $\Delta S = +\Delta Q$ rule is not satisfied. (Chance that rule is satisfied and our results are due to a statistical fluctuation is about 3.5%). For the ratio of $\Delta S = -\Delta Q$ to $\Delta S = +\Delta Q$ amplitudes we find $+0.5^{+0.11}_{-0.19}$. We thus agree with the results of Ely et al.[4]

$\pi^+ + p \rightarrow \Sigma^+ + K^+$ Near Threshold

Analysis of about 400 events has been completed and submitted for publication.[5] Both s and p waves are present, within 20 MeV/c of threshold. These results will be compared with threshold dependence of $\pi^- + p \rightarrow \Sigma^0 + K^0$ to look at the question of charge independence near threshold.

$\pi^{\pm} + p \rightarrow \Sigma^{\pm} + K^{\pm}$ at 1170 MeV/c

The reaction $\pi^+ + p \rightarrow \Sigma^+ + K^+$ has been studied at 1170 MeV/c in the 72-inch liquid hydrogen bubble chamber. An analysis of 251 events gave a total cross section of 0.205±0.014 mb, and values of a ${}^0\overline{P}_{\Sigma^+} = 0.62 \pm 0.19$, a ${}^+\overline{P}_{\Sigma^+} = -0.18 \pm 0.13$. The s-, p-, and d-wave amplitudes were determined from analysis of the differential cross section and of the polarization of the Σ^+. Based on extrapolation of s and p amplitudes obtained near

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[4] R. P. Ely, W. M. Powell, H. White, and others, Phys. Rev. Letters 8, 132 (1962).

[5] Fernand Grard and Gerald A. Smith, A Study of the Reaction $\pi^+ + p \rightarrow \Sigma^+ + K^+$ Near Threshold, Phys. Rev. (to be published).

threshold in a previous experiment in which angular distribution, polarization, and energy dependence were used, an attempt has been made to resolve the Minami ambiguity in the amplitudes of this experiment. The results have been submitted for publication.[6] They will be used in conjunction with the π^- results at the same momentum to check charge independence. The π^- data are not yet completely measured.

Pion Experiments (72-Inch Chamber)

Strange-Particle Resonant States at 2.1 BeV/c

Approximately 160,000 pictures of high-energy π^- (1.55 to 2.23 BeV/c) have been taken, using the K72 beam channel during time not scheduled for K^- running. Additional running is continuing.

An analysis of 30,000 of these pictures has so far been completed. It is found that the 1405-MeV/c^2 Y_0^* is produced strongly in 2.1-BeV/c $\pi^- + p$ interactions leading to the final states ($\Sigma^+\pi^-$ or $\Sigma^-\pi^+$) K^0. The distribution of events in the region of the peak suggests that it be identified with a bound $s_{1/2}$ state of the $\bar{K}$-N system. In addition, an enhancement appears in the mass region $M_{\Sigma\pi} = 1510$ to 1560 MeV/c^2 owing to the production of the I = 0 1520-MeV/c^2 resonant state. A study of the mass distribution for the $K\pi$ system leads to an observed width $\Gamma = 60 \pm 5$ MeV/c^2 for the K^* resonance. Finally, some evidence has been found for the existence of a resonant state of the $K\pi$ system at $M_{K\pi} = 730$ MeV/c^2.

Analysis of Four-Prong Events

An analysis of four-prong events produced by 2.03-BeV/c π^- mesons in hydrogen yielded 633 events of the type $\pi^- + p \rightarrow \pi^- + p + \pi^- + \pi^+$, (1)

283 events of the type $\pi^- + p \rightarrow \pi^- + p + \pi^- + \pi^+ + \pi^0$, (2)

and

134 events of the type $\pi^- + p \rightarrow n + \pi^- + \pi^+ + \pi^- + \pi^+$. (3)

All these reactions are strongly influenced by the 3/2, 3/2 pion-nucleon resonance. No evidence for the formation of the ρ meson has been found. In Reaction (2) there are 12±4 events of the type $\pi^- + p \rightarrow \pi^- + p + \eta$ and about 70±20 events of the type $\pi^- + p \rightarrow \pi^- + p + \omega$, where η or $\omega \rightarrow \pi^+\pi^-\pi^0$. The effective mass distributions of the four pions in Reactions (2) and (3) do not show any statistically significant peaks in the mass interval 900 to 1200 MeV/c^2.

Low-Energy $\pi^- + p$ Interactions

Data on π^--p interactions have been taken with the 72-inch chamber at $p_{\pi^-} = 470$, 530, 575, 610, 676, 730, 800, and 850 MeV/c. Analysis of these data is in progress for the lower five momenta for the reaction $\pi^- + p \rightarrow \pi^- + \pi^+ + n$. The final results at 470 MeV/c show a large enhancement of phase space in the vicinity of a dipion mass of 420 MeV/c^2, which is suggestive of a broad strong I = 0 pion-pion interaction. The enhancement does not appear in the 610-MeV/c data, but it may be obscured by the 3/2, 3/2 pion-nucleon isobar.

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[6] Frank S. Crawford, Jr., Fernand Grard, and Gerald A. Smith, Production of Σ^+K^+ by (π^+, p) Interaction at 1170 MeV/c, submitted to Phys. Rev.

Antiproton Experiments

Two-Prong Events (72-Inch Chamber)

An analysis of two-prong interactions of 1.61-BeV/c antiprotons in the 72-inch hydrogen bubble chamber is in progress. The angular distribution of the large-angle elastic scatterings has been studied. The elastic scattering cannot be adequately fitted with a four-parameter optical model. An approximately 90% pure sample of 150 $\bar{p}p\pi^0$ events and less pure samples of $\bar{p}N\pi^+$ and $pN\pi^-$ events are being studied. Approximately one-half the 300 events that fit $\pi^+\pi^-\pi^0$ are not truly three-body events. Program FAKE is being used to understand how to estimate and eliminate these misinterpreted events.

Antiproton-Proton Cross Sections (15-Inch Chamber)

In collaboration with the Lofgren group, antiproton-proton cross sections have been measured at lower energies than heretofore accessible through the use of the Lawrence Radiation Laboratory 15-inch liquid hydrogen bubble chamber. Interactions were studied in four energy intervals by insertion of suitable degraders in an electrostatically separated beam of 245-MeV antiprotons. Approximately 4000 antiprotons were incident in each of the energy intervals 45±20 MeV, 90±20 MeV, 145±17 MeV, and 245±20 MeV. For the total cross sections at these energies, we find 281±46, 185±13, 163±12, and 118±9 mb. The elastic-scattering cross sections are 80±10, 65±6, 52±6, and 45±5 mb, respectively. The calculations by Ball and Fulco[7] are in reasonable agreement with the measured differential cross sections. The total cross sections at 145 and 245 MeV agree with those recently measured with counters by Coombes et al.,[8] while the elastic-scattering cross sections are systematically 15% lower than those obtained in the counter measurements.

DATA REDUCTION

Programming and Computer Efforts

The necessary programs for use with the card-controlled mode of operation of the measuring projectors are now working. A new program called PANAL has been written to take the output from the measuring projectors. This program performs checks on the format of the measurements, matches the track images on the three views, and selects the pair of views that should be used in the track reconstruction. PANAL is also used as an event-ordering and tape-merging facility for easier tape handling. The programs PANG and KICK have been merged to form a program called PACKAGE which performs the track reconstruction and kinematic analysis of the events. The EXAMIN program has been further enlarged, and the selection programs READX and SUMMEX are being used to help the physicists extract physics results from the data. Programs for a library

[7] J. S. Ball and J. R. Fulco, Phys. Rev. 113, 647 (1959).

[8] Charles A. Coombes, Bruce Cork, William Galbraith, Glen R. Lambertson, and William A. Wenzel, Phys. Rev. 112, 1303 (1958).

system, which eliminate many of the bookkeeping problems involved in handling large numbers of events, have been written and are now working satisfactorily.

Preliminary work has started on the "QUEST" project. This is a system for operating a measuring projector on line to the IBM 709 or 7090 computer. It will have a provision whereby the operator, probably a physicist, can interrupt any program on the computer. He can then obtain analysis results on the event being measured by using a special version of the PACKAGE program. This system is intended for the analysis of unusual events which cannot be understood except by complicated kinematic calculations.

Program FAKE, a Monte Carlo program to simulate the output of the PANG track-reconstruction program, is operating, though some of its features are not yet operational. This program generates events which are distributed in the bubble chamber in a realistic fashion. Up to six-body final states can be generated with a phase-space distribution or according to any matrix element the user wishes to write. Realistic errors are assigned to all measured quantities and then these quantities are modified to simulate actual errors. This program can be used to test the analysis system, to find out how often an event of one type is identified as another event, and to find biases in the methods of analyzed events.

An Electronic Analog System for Kinematical Analysis of Interaction Vertices

Typically the majority of bubble chamber events that have been selected visually by simple topological criteria "fit" one or more of the common hypotheses associated with the topology. Usually, however, there is also a residue of events, amounting to perhaps 10% of the total number of events analyzed, which for nontrivial reasons do not fit any of the common hypotheses. These consist of rare reactions not considered among the common types, misinterpretations of the actual topology, etc. It would be a great advantage in treating these failures to have immediate feedback so that a physicist could acquanint himself with a problem event and lay it to rest in a single operation.

An electronic analog of the KICK-GUTS part of the analysis system was conceived about a year ago as a means of providing such a facility, and a prototype is now nearing completion. It was dubbed PEBL (momentum, energy balance). Inputs to the analog—momenta, angles, and errors—are presently obtained from the geometrical reconstruction programs. The inputs are inserted digitally in a decimal system by manual switching at present, with provision for semi-automatic insertion by a punched card or tape-reading machine if such a procedure should prove to be desirable in the future. Output is obtained digitally in either visual or printed form, one quantity at a time or in groups by automatic scanning of programmed formats. The system is a fully automatic steady-state analog requiring a few seconds to reach equilibrium. Very little specialized technical know-how should be required to use the machine.

All design has been completed and all subsystems have been reduced to printed circuitry. Expansion to a system with more tracks and vertices will involve mainly copywork. Provision has been made to accommodate simultaneous two-vertex fits. Tests to date have included successful operation with three-dimensional momentum constraints. Completion of the prototype involves mainly the addition of the energy constraint (fully tested independently) and minor improvements of the read-out system. Before summer 1962 PEBL should be useful.

Franckenstein System

The 72-inch liquid hydrogen bubble chamber scanning and measuring system is now fully operational, with four measuring projectors and ten scanning projectors. The two measuring projectors brought into operation during the past year are partially controlled by IBM cards. This relieves the operators of many of the decisions that have to be made during measuring, and has led to fewer errors and an increase in speed of about 20%. The system is now capable of making about 90,000 measurements per year. Two scanning projectors have been lent to UCLA for the cooperative effort on the K72 experiment.

The 15-inch bubble chamber data-handling system has continued to operate throughout the year. It now consists of two measuring projectors and two scanning projectors; one measuring projector and seven scanning projectors are on loan to other groups in the Laboratory. The work load on this system is gradually decreasing because no new 15-inch exposures have been made during the past year.

The Spiral Reader

All electronics are installed and except for the film-handling system the machine is operational. The film-handling system is being debugged at this time.

A preliminary version of the FILTER program is working satisfactorily on simple clean events.

The system is providing the necessary information for the final development of the production program.

The SMP System

A working model of a combined scanning and measuring projector (SMP) has been built and is being tested on-line to the IBM 709 computer. Measurements of track coordinates go directly into the memory of the computer as the result of the operator's moving a periscope along the tracks of the event. The measurement accuracy has been determined to be better than 3 μ, and the automatic bubble-detection circuits have picked up tracks clearly even on low-quality film.

A plan for connecting ten such machines to the direct data channel of the IBM 7090 computer has been worked out and a computer program is being written for processing the interrelated data. In this plan the computer program will guide the operator through the steps of the scanning and measuring operations and test the results of each step as he proceeds. In order to test the plan, three operational models of the SMP have been designed and are being constructed, along with circuits for connecting them to the direct data channel of the IBM 709.

Data-Reduction Operation

Personnel

The total effort in Full Time Equivalents was 56 for November 1961 and rose to 61-1/2 in April 1962.

Scanning

During this 6-month period, the following scanning of 72-inch bubble chamber film was done:

Experiment	Scan	Number of rolls
4 (associated production)	first (π^+)	59
4 (associated production)	first (π^-)	115
6	first (π^-)	66
6	second (π^-)	55
7	first (K^-)	149
7	second (K^-)	182
7	selective (K^-)	229
8 (started 1/17/62)	first (π^-)	88
Total 72-inch bubble chamber scanning		943

Scanning of 15-inch bubble chamber film consisted mostly of looking at remeasurements, resolving conflicts, and counting beam tracks.

Measuring

The following is a summary of the measuring activity during this half year:

Meas. Proj.	BC	Meas. Hrs.	Instr. Hrs.	No. of Events
IA	15-inch	1040	15	6,068
ID	15-inch	613	35	5,131*
TOTAL	15-inch	1653	50	11,199
IIA	72-inch	2776	51	13,426
IIB	72-inch	2446	107	11,529
IIC	72-inch	1937	69	9,056
IID	72-inch	1374	69	7,465
TOTAL	72-inch	8533	296	41,476

*Includes beam track measurements for Expt. 11.

BUBBLE CHAMBER OPERATION AND DEVELOPMENT

72-Inch Chamber Operations

During this report period, the 72-inch chamber continued to operate for the K72 experiment begun earlier. The experiment will continue into June of this year, until the shutdown of the Bevatron. Thus far, approximately 500,000 pictures have been photographed of K^-+p interactions. The chamber has been utilized for π-meson exposures during the "off" periods of the K72 experiment, resulting in an extremely high utilization of the 72-inch chamber. Approximately 250,000 photographs of π^-+p interactions have been taken during such periods.

25-Inch Chamber Development

The pace of development of the 25-inch chamber has been set so as to have this new device available for experimental physics when the Bevatron resumes operation next year after the shutdown for Bevatron improvement. The main effort has gone into testing critical components of the chamber. A low-temperature rapid-cycle bellows test device was designed and constructed. This facility has been used to establish fatigue limits for the larger expansion bellows to be used. An optical model of the illumination system has been constructed.

Experiments with the 25-inch chamber will, of course, be chosen to take best advantage of the particular capabilities that it will offer, the most important among these being mobility and high precision. Its mobility should be comparable to that of the old 15-inch chamber; that is, it will be possible to optimize and change the location of this chamber on the basis of experimental considerations without severe restrictions stemming from great bulk. The precision of the 25-inch chamber should be as good as or better than that obtained with the 72-inch chamber. This chamber will be a general laboratory instrument and will be used by a number of experimental groups.

SUPERCONDUCTIVITY STUDIES

The Superconductivity Studies Group has continued in its primary effort toward the development of high-field magnets. In addition, some effort has been given to the study of applicable superconductors, principally in terms of understanding the behavior of NbZr alloy wire. Details of this work are available in the references cited at the conclusion of this section.

We have made a 40-kilogauss solenoid 1/2 in. i. d. by 4.5 in. long for study and for use in the laboratory. This coil is wound with 0.010-in. formvar-insulated Nb-25 a/o Zr wire, each layer of which is insulated with Mylar tape. The coil consists of three windings. In the present scheme of operation each of these is shunted by a silicon diode connected in reverse polarity. When used with this circuitry, the magnet has a repeatable quenching current of 16.1±0.3 amp.

This circuit operates by providing a temporary energy storage in the form of the mutual inductance between windings so that, when one winding quenches on raising the current, it is able to transfer its current to another until it can recover; thus, the circuit has the effect of smoothing out excitations associated with the changing current which would otherwise be sufficient to drive the magnet "normal." In addition to removing the uncertainty of operation and thus avoiding the helium loss and possible coil damage associated with quenching, this technique has the useful property of diminishing the problem of local, resistive heating by forcing uniform quenching through the mutual coupling.

We are currently constructing a 2.5-in. i. d. solenoid which will attain an estimated 55 kG at its center. This magnet will consist of two coaxial coils, the inner one a pancake pair, the outer one a single solenoid 4.5 in. i. d. by 6 in. long. The inner coils, one of which has already operated at 27.5 kG, are intended to be engineering test coils, useful for studying winding techniques, energy-handling techniques, and field-homogeneity problems. The outer coil is under construction and should be finished and operating within a month. In addition to its utility for study, this magnet will be useful for measurements and will afford a basis for constructing a Nb_3Sn/NbZr hybrid system to attain perhaps 100 kilogauss in a 1/2-in. i. d. hole.

In measurements in the 40-kilogauss solenoid, we have discovered the effects of the diamagnetism of and the flux penetration into the superconducting windings. These include an anomalous inductance at helium temperatures and the existence of a remnant field once the magnet has been raised above a field value corresponding roughly to the bulk critical field. These observations will be reported at the Evanston Meeting of the American Physical Society in June.

We have done some preliminary work in studying the proximity effect which gives rise to the "20-amp catastrophe" in tightly packed windings, and find that a decrease in the packing fraction to 0.1 gives a quenching current of 35 A. This work will continue as soon as the Campus magnet is back in operation.

In addition to this work on magnets, we have studied the effect of heat treatment at an intermediate stage of the cold-reduction process on Nb 25 alloy a/o Zr. As was anticipated from earlier work, the critical current density of this material can be enhanced by 30% for fields between 30 and 65 kG when it is subjected to a 1-hour intermediate heat treatment at the optimum temperature of 700°C. Not even a qualitative understanding of how this effect comes about is presently available. We are working in collaboration with Professor G. Thomas of the Department of Mineral Technology in an effort to relate superconducting properties to the electron microscopic structure of this alloy.

We have fabricated several small flux concentrators both from Nb and from Nb_3Sn. These are similar in geometry to those which utilize the diamagnetic effect of eddy currents to produce a high local field, but suffer in comparison with their operation because of the liability of hard superconductors to flux pentration. These devices show useful field-multiplication ratios until the applied field exceeds the bulk critical field of the material. At this point the magnetization of the superconductor begins to depart from perfect diamagnetism and the material does not support the field stresses necessary to produce efficient concentration.

The group strength is presently six men. Group reports for this period include a paper presented to the AIME in February.[9]

[9] Paul R. Aron and Harley C. Hitchcock, Anomalous Critical Currents in Nb-25 a/o Zr Wire, J. Appl. Phys. (to be published).

PHYSICS RESEARCH

Walter H. Barkas in charge

STRANGE-PARTICLE RESEARCH

Leptonic Decay of Hyperons

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

A continuing program of study of the decay modes of Σ hyperons (Phys. Rev. 124, 1209, 1961) has led to the observation of an event for which the only probable interpretation is $\Sigma^+ \rightarrow n + \mu^+ + \nu$: a violation of the $\Delta S = \Delta Q$ rule. A thorough analysis of this event has been carried out, and further examples of leptonic Σ decay are being sought.

Energy-Momentum Balance in the Reaction $K^- + p \rightarrow \Sigma^\pm + \pi^\mp$

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

In order to resolve an apparent anomaly in the energy and momentum balance in the reaction $K^- + p \rightarrow \Sigma^- + \pi^+$,[1] a redetermination of the ranges, energies, momenta, and masses of the particles is being continued, and is nearly completed. The ranges were measured for

The proton from $\Sigma^+ \rightarrow p + \pi^0$, (1)
The pion from $\Sigma^+ \rightarrow n + \pi^+$, (2)
The pions and hyperons from $K^- + p \rightarrow \Sigma^\pm + \pi^\mp$. (3)

A critical examination of the range-energy relation in the region τ (= T/M) ≤ 10 MeV is in progress because of its importante to Reactions (1) and (3). By measuring the ranges of p, d, t, He^3, He^4, and Li^6 ions of the same magnetic rigidity [$(\Delta\rho)/\rho \leq 10^{-4}$], the shape of the range-energy relation can be deduced. The range measurements at four different magnetic rigidities are complete and the data are being analyzed. To date, no significant difference has been found between these measurements and the existing range-energy relation.

[1] John Dyer, Charged Σ-Hyperon Production and Decay: Energetics, Lifetimes, and Branching Ratios (thesis), UCRL-9450, Nov. 1960.

K^--Meson Reactions in Complex Nuclei

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

The broad purpose of this program is a study of the role that Σ-π, Λ-π, and other resonances play in the capture of K^- mesons in complex nuclei. In K^--capture events at rest, we earlier found a narrow peak when the "invariant mass" of ($\Sigma^{\pm}$, $\pi^{\mp}$) systems was plotted. Our best value of this Y_0^* mass, based on 239 events at rest and 35 in flight, now is 1405±1 MeV. The full width at half maximum, which includes our experimental resolution, is 20 MeV.

To complete the analysis of K^--meson interactions at rest,[2] 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. These 80 momentum determinations were performed by multiple scattering with the Koristka MS-2 digitized microscope and the Cooke scattering microscope. The former data were processed with the aid of the 650 IBM program SCAT. Some 17 events are currently in process.

To complete work on the spectrum of secondaries from K^--meson stars at rest, ranges of some 20 high-energy pions from K^- stars involving hyperfragments were measured (see D below).

Work is proceeding on the determination of the momentum of some 35 Σ-hyperon events that do not come to rest. This analysis is being carried out by gap and blob-length measurements obtained from a semiautomatic ionization-measuring machine.

Hyperfragment Production Process

Piyare L. Jain, Jack W. Patrick, and Walter H. Barkas

To better understand the modes of production of hyperfragments, we analyzed K^- stars in which a hyperfragment and a pion were associated.

The ranges of negative pions enabled us to distinguish between the primary process $K^- + n \rightarrow \Lambda + \pi^-$ and such reactions as $K^- + p \rightarrow \Sigma^0 + \pi^0$. The latter reactions presumably are followed by charge exchange of the π^0 and conversion of the Σ to a Λ by interaction with nucleons.

It was found that sometimes π^+ mesons also are emitted. There is every reason to believe that they are produced in the process $K^- + p \rightarrow \Sigma^- + \pi^+$ followed by $\Sigma^- + p \rightarrow \Lambda + n$.

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[2] Physics Division Semiannual Report, UCRL-10113, March 5, 1962, p. 16.

PION RESEARCH

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

The measurement of the π^0 mean life was nearly concluded in the preceding report period. Final evaluation of systematic effects and statistical errors have now been made and the value quoted is

$$\tau_{\pi^0} = 2.0^{+0.5}_{-0.3} \times 10^{-16} \text{ sec.}$$

HEAVY-ION RESEARCH

Neutrons Produced in Heavy-Ion Reactions

William Simon

Measurements of the neutron spectra from heavy-ion-induced interactions are being continued. Measurements for 160- and 142-MeV O^{16} ions on a thick Au target have been completed. These include neutrons with energies 2 to 10 MeV. Additional measurements are being made to extend the range of neutron energies to 1 to 14 MeV. The neutron yield for 160-MeV O^{16} ions on a thick Au target at zero degrees in the laboratory system is 4×10^{-5}/MeV-sr at a neutron energy of 2 MeV, and decreases somewhat more strongly than exponentially to a value of 1.6×10^{-6}/MeV-sr at 10 MeV.

Analysis of the Charged Particles from O^{16} Interactions

Donald Reames

Examination of the spectra of charged particles produced at 0° to the O^{16} beam in interactions with Al, Ni, and Au is continuing. An attempt is now being made to resolve the isotopes of higher-Z products, and it is hoped that the differential cross sections for production of all nuclides in the range Z = 1 to 4 (and possibly 5) will be determined. This would then allow the spectra seen to be compared with the predictions of evaporation theory and thus possibly provide insight into the production mechanism.

An attempt to improve the corrections for energy loss in the thick target--i.e., to better determine the spectra at the interaction--is also under way.

Exposures have been made of the angular distributions from 0° to approximately 15° and also near 180°, for 142- to 167-MeV O^{16} on Al. The distribution of higher-energy protons and α particles will thus be examined to verify the expected inconsistency of this distribution with the evaporation model and determine the extent of direct or grazing interactions.

Angular Correlation of Light Particles

William Simon and Harry H. Heckman

Compound nuclei formed in heavy-ion interactions are characterized by their high angular momentum. It is expected that directions perpendicular to the angular momentum vector of the compound system are preferred in the evaporation of particles. The angles, projected in the plane perpendicular to the beam direction, of particles evaporated from the same nucleus should then be correlated, with angles near 0° and 180° preferred.

Emulsions were exposed to a beam of 166-MeV O^{16} ions perpendicular to the emulsion surface. The projected angles between the particles from 1200 three-, four- and five-prong events were measured. The results are: 799 angles between 0° and 60°; 762 between 60° and 120°; and 1358 between 120° and 180°. The high number of angles between 120° and 180° is quite possibly a result of interactions with light emulsion nuclei in which compound nuclei are not expected to form, and recoil effects are large. No definite conclusions can be drawn from these results. Emulsions with 0.25-mil Au foils on their surfaces have been exposed to O^{16} ions in a similar way. Such studies of the interactions of O^{16} ions with the Au nuclei will eliminate the contamination from light nuclei.

Fission Reactions Induced by Heavy Ions

William S. Simon

Sikkeland et al. have reported that an analysis of the momentum of the fission fragments resulting from the bombardment of U^{238} foils by 166-MeV O^{16} ions indicates that many of the fission reactions result from the transfer of a particle of mass ≈ 4 by the O^{16} nucleus.[3] Studies of these fission reactions in U^{238}-loaded emulsions may yield the following types of findings:

(a) verification of the transfer mechanism by observation of the stripped particle;
(b) the exact fraction of all fissions resulting from the transfer mechanism;
(c) the identity of the beam particle after transfer;
(d) the momentum of the fissioning nucleus.

Studies are being made to obtain a maximum homogeneous loading of U^{238}. This will be necessary in order to get reasonable statistics without excessive scanning.

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[3] Torbjørn Sikkeland, Eldon L. Haines, and Victor E. Viola, Jr., Phys. Rev. 125, 1350 (1962).

ENERGY SPECTRUM OF GEOMAGNETICALLY TRAPPED PROTONS

Harry H. Heckman

An article concerning the energy spectrum of geomagnetically trapped protons was published.[2] An abstract of this article follows:

The energy spectrum of protons in the inner Van Allen radiation belt has been measured for energies greater than 12 MeV. The spectrum was measured by using nuclear-track emulsions irradiated during the flight of an Atlas missile from Cape Canaveral on October 13, 1960. Above 100 MeV the data are in agreement with the albedo-neutron hypothesis. The spectrum falls below the calculations of Freden and White at high energies. The theory of Lencheck and Singer gives an improved fit to the data when the cutoff energy parameter has a value of 650 MeV. The anomalous behavior in the spectrum below 80 MeV, observed in a previous flight on July 21, 1959, is confirmed. The spectrum in this experiment departs significantly from the above calculations for energies less than 80 MeV. A maximum is reached at about 35 MeV, with a minimum indicated near 20 MeV. Further investigations are necessary to decide whether the spectrum below 80 MeV represents an equilibrium condition or a transient phenomenon attributable to solar protons. Mass measurements were carried out on 783 tracks with residual ranges greater than 5 mm. Five deuterons were found.

VIDEO TRACK ANALYZER

Harry H. Heckman and Walter H. Barkas

Development and construction have been continued on a television-equipped microscope for the rapid analysis of particle tracks. The video-optical system is designed to translate the video signals from a sequential scanning TV camera that views a microscope image of a particle track into the following information: (a) number of blobs; (b) mean gap length; (c) mean blob length; (d) distribution of blob or gap lengths; and (e) mean track width. This information will be displayed visually or punched into IBM cards (or both). It is expected that with this instrument essentially all the information in a particle track can be obtained at a rate that is several orders of magnitude greater than the rate achieved by present techniques.

As part of the development program for the instrument, two 10-pound emulsion stacks have been flown at altitudes greater than 100,000 feet for times up to 8 hours (one launched in Texas, the other at Sioux Falls, South Dakota) to obtain relativistic and nonrelativistic heavy ions for charge and mass analysis. The stacks were constructed from emulsions with widely varying sensitivity, i.e., from electron-sensitive emulsion to emulsions sensitive only to stopping heavy multicharged ions. The first measurements to be done with the track analyzer will therefore be to evaluate the properties of the various Ilford emulsions and to relate these properties to the problem of determining the charge and mass of particles from their ionization tracks.

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[2] A. H. Armstrong and Harry H. Heckman, J. Geophys. Research 67, 1255 (1962).

PHYSICS RESEARCH

Kenneth M. Crowe in charge

As account of work done during this period may be expected to appear in the next semiannual report.

THEORETICAL GROUP

David L. Judd

Part A: May through October 1961

STRONG INTERACTIONS

S-Matrix Theory

It is well known that efforts to provide a rigorous basis for modern dispersion-theoretic calculations starting from field-theoretic axioms have not been successful. Also the field-theoretic axioms themselves are open to considerable doubt, as they are statements of abstract mathematical relationships, rather than physical principles, and it has not been possible to develop their consequences to a point permitting experimental tests. An alternative approach based directly on the S matrix and an assumed analyticity property was explored. The axioms are the physical principles of superposition, particle observables, Lorentz invariance, and conservation laws, plus the assumption that--as in scattering from a sum of Yukawa potentials--the physical sheet, including its boundaries, has only the singularities required by unitarity. Finally, it was assumed that the functions at physical-type points on the physical sheet correspond to processes actually occurring in nature. These assumptions are sufficient for the derivation of the needed properties of the S matrix usually derived from field theory, and the latter can be dispensed with. In particular the substitution rule, symmetry laws, and the CPT theorem follow. If self-conjugate combinations of particle and antiparticle amplitudes are not in principle unobservable, then the normal connection between spin and statistics follows. The work is described in two reports.[1] (Henry P. Stapp)

The Stapp S-matrix theory has been applied to the study of the scalar vertex. An approximation method, suggested by Stapp, is demonstrated to be equivalent to perturbation theory. Thus the conclusions reached by Karplus, Sommerfeld, and Wickmann[2] regarding the occurrence of anomalous thresholds are also consequences of the Stapp formalism. (John B. Hutchins, Joseph V. Lepore, and Robert J. Riddell, Jr.)

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[1] Henry P. Stapp, Derivation of the CPT Theorem and the Connection Between Spin and Statistics from Postulates of the S-Matrix Theory, Phys. Rev. 125, 2139 (1962);

Henry P. Stapp, Lectures on the S-Matrix Theory (UCRL-9875, Sept.-Nov. 1961), (to be published in book form by W. A. Benjamin, Inc.).

[2] Robert Karplus, Charles M. Sommerfeld, and Eyvind H. Wickmann, Spectral Representations in Perturbation Theory, Phys. Rev. 111, 4, 1187 (1958).

A study was made of the unitarity condition and its application in determining the singularities and discontinuities of the S matrix. (Cecil E. Jones).

Work was done on the group theoretical determination of the invariant scattering functions in S-matrix theory.[3] (Asim O. Barut)

S-Matrix Theory and Strongly Interacting Particles

In collaboration with Steven C. Frautschi--and with assistance from Marcel Froissart and Stanley Mandelstam--the investigation of the strong-interaction S matrix was continued. The major conclusion was that poles in the complex angular momentum plane--of the type discovered by Regge for nonrelativistic potential scattering--were likely to be of general occurrence and of crucial importance. These poles not only are responsible for the stable and metastable particles but also they control high-energy scattering in a direct and simple way. Furthermore they allow a simple and plausible formulation of the principle of maximum strength for strong interactions, which should eliminate arbitrary dimensionless parameters from the theory together with the elementary-particle concept. The work is described in three publications.[4] (Geoffrey F. Chew)

The properties of partial-wave amplitudes as a function of the angular momentum considered as a complex variable was investigated together with the application of these properties to elementary particle physics. It was shown how the partial-wave amplitude can be formally defined, for all angular momenta, in a unique and useful way, and the significance of this formal definition has been considered for certain special cases. In particular, for Yukawa potential scattering, the region of analyticity was extended beyond that previously assumed, and certain interesting symmetry properties have been revealed. For relativistic scattering an explicit expression for the

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[3] Asim O. Barut, Formulation of the Scattering Functions in Terms of the Unitary Representations of the Inhomogeneous Lorentz Group (UCRL-9963, Nov. 1961), to be submitted to Phys. Rev.

[4] Geoffrey F. Chew and Steven C. Frautschi, Potential Scattering as Opposed to Scattering Associated with Independent Particles in the S-Matrix Theory of Strong Interactions, Phys. Rev. 124, 264 (1961);

Geoffrey F. Chew, Steven C. Frautschi, and Stanley Mandelstam, Regge Poles in π-π Scattering, UCRL-9925, Nov. 1961;

Geoffrey F. Chew and Steven C. Frautschi, Principle of Equivalence for All Strongly Interacting Particles Within the S-Matrix Framework, Phys. Rev. Letters 7, 394 (1961).

partial-wave amplitude, defined for some region of angular momentum, was shown to satisfy the formal definition. This has the property of being "physical" only for alternate ℓ values, in accordance with the idea of "j parity" previously postulated by several authors. This work has been prepared for publication; extensions of it are proposed. (Euan J. Squires)

The analytic continuation of the scattering amplitude in complex angular momentum was investigated, and in particular numerical calculations were employed to study certain soluble potentials (a report is being prepared). The theory of complex angular momenta was used to define and study the so-called virtual particles.[5] (Asim O. Barut)

Investigation of the scattering of pions by pions, using the Mandelstam representation, was started in July. Preliminary results obtained with an IBM 709 code showed that Regge poles occur naturally as a result of analyticity and unitarity. Regge trajectories for several relativistic potentials were obtained. In collaboration with Cecil Tate the numerical solution of the Schrödinger equation for a variety of potentials has been started and preliminary results on the corresponding Regge trajectories obtained for a Yukawa potential. (Philip G. Burke)

A study of Regge poles for Coulomb scattering was conducted during this period. The results have been submitted to Physical Review.[6] (Virendra Singh)

In an attempt to characterize the interaction range, the Schrödinger scattering of localized "in packets" into "out packets" by a class of potentials (not limited to central potentials) that fall off a large distance was studied in detail. The S-matrix formalism for the above-mentioned Schrödinger scattering was expressed in terms of wave packets, and the associated expression of the cross section derived. The localization (or the characterization of the interaction range) of the scattered out packets ψ_0 is expected to be governed by the exponential rate of fall-off of the class of potentials. The studies on the localization of the scattered out packets ψ_0 is not yet completed; the methods used involve the determination of the region of analyticity of the Fourier transform of the scattered out packets, $\psi_0(\bar{p})$, in terms of the three complex components of the momentum variable $\bar{p}$. From the analyticity region in $\bar{p}$ it is hoped to deduce the rate of fall-off of $\psi_0(\bar{x})$ in the $\bar{x}$ space for large $|\bar{x}|$. (Jack Wong)

Various Applications of S-Matrix Theory

The nucleon-nucleon scattering amplitude was studied within the framework of the strip approximation. Ten independent functions are required to describe the amplitude, and it was found convenient to use for these the helicity amplitudes so modified that they satisfy the Mandelstam representation. Asymptotic bounds to the behavior of these amplitudes were derived,

[5] Asim O. Barut, Virtual Particles, UCRL-9993, Dec. 1961.

[6] Virendra Singh, Analyticity in the Complex Angular Momentum Plane of the Coulomb Scattering Amplitude, UCRL-9972, Dec. 1961.

by use of the limitations imposed by unitarity and by assumption of the dominance of diffraction scattering at high energies, and these have been utilized to limit the number of "allowed" single-spectral functions. There is a corresponding limitation on the types of dynamically independent one-particle states, which admits the pion but excludes the deuteron: the deuteron must be considered as a bound state. The unitarity equations, in which only two-particle intercalated states are retained, have been derived explicity in both the nucleon-nucleon and nucleon-antinucleon channels. The nucleon-antinucleon equations express a portion of the double-spectral functions in terms of the pion-nucleon amplitudes; the nucleon-nucleon equations express another portion of the double-spectral functions through coupled integral equations. The work has been prepared for publication.[7] (John M. Charap, Elihu Lubkin, and Antonio Scotti)

Work on obtaining an effective-range formula for nucleon-nucleon scattering, which involves making approximations only of functions that are already known from the general framework of the theory, was completed.[8] At the same time work was begun on calculating the nucleon-nucleon two-pion exchange potential by using the Mandelstam representation, and taking experimental data on pion-nucleon, and, to a lesser extent, pion-pion scattering. This work is still in progress. (Louis Balázs)

The single-virtual-particle exchange model[9] was applied to the inelastic process of $2\pi \rightarrow 4\pi$. The energy dependence of the inelastic cross section was determined analytically at threshold and at high energies, where integration of the expression[10] for the differential inelastic cross section is tractable providing a scattering-length formula for the pion-pion elastic scattering is assumed. A numerical program was written for intermediate energies, but the actual computing was not carried out. An attempt is being made to understand the relation between this model and the strip-approximation model of S-matrix theory due to Chew and Frautschi.[11] The latter model with

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[7] John M. Charap, Elihu Lubkin, and Antonio Scotti, Theory of Nucleon-Nucleon Scattering in the Strip Approximation to the Mandelstam Representation (UCRL-10028, Dec. 1961), submitted to Ann. Phys. N. Y.

[8] Louis A. P. Balázs, Dispersion-Theoretical Fitting of Nucleon-Nucleon Scattering (submitted to Phys. Rev.).

[9] F. Salzman and G. Salzman, Phys. Rev. 121, 1541 (1961).

[10] Equation (1) in reference 1.

[11] G. F. Chew and S. C. Frautschi, Phys. Rev. 123, 1478 (1961).

suitable simplifications is shown to be identical to the single-particle exchange model only insofar as the total inelastic cross section is considered. However, this relation between the models for the cross sections in a certain differential form is yet to be understood. Once this obscurity is removed the results will probably be generalized to include the charge degree of freedom. (Martial L. Thiebaux, Jr.)

The contribution of s-wave $\pi\pi$ interaction to inelastic πN scattering was calculated in the strip approximation to the Mandelstam representation. The effect was found to be of the right order of magnitude at threshold, but did not rise sufficiently rapidly with energy. (B. M. Udgaonkar and Virendra Singh)

A self-consistent calculation of Λ and Σ decays was carried out by using an S-matrix approach retaining only baryon poles, in an attempt to see if one could predict the angular momentum state involved in the decay $\Sigma^+ \rightarrow n+\pi^+$. The calculation favored an S-wave decay.[12] (Virendra Singh and Bhalchandra M. Udgaonkar)

Work was done on using Regge poles to determine the behavior of cross sections at high energies. This work, which is still in progress, consists in making a theory for the difference in the high-energy p-p and $\bar{p}$-n cross sections, which difference will be governed by Regge poles of G parity. (Cecil E. Jones)

An investigation was made of high-energy cross sections and their relation to Regge poles.[13] (UCRL-9974). A detailed fitting of all available total cross sections of $\pi^{\pm}$-p, $K^{\pm}$-p, p-p, and $\bar{p}$-p is now being undertaken. It was shown, from an understanding of the relation between asymptotic cross sections and Regge poles, that nuclear-nucleon cross sections should approach $\sigma_{NN} \cdot A$ (rather than the previously believed $A^{2/3}$ dependence) at extreme energies. This latter work will be published jointly with M. Gell-Mann. (B. M. Udgaonkar)

Analyticity of the S matrix as a function of angular momentum was applied to the charge-exchange n+p scattering. The results are expected to be useful at energies larger than 2 BeV. It has been conjectured that this charge-exchange angular distribution can be explained by a system with the quantum numbers of the ρ meson. An experiment is in progress at

[12] Virendra Singh and B. M. Udgaonkar, Self-Consistent Model for Nonleptonic Decays of Σ and Λ Hyperons, Phys. Rev. (to be published).

[13] Bhalchandra M. Udgaonkar, Phys. Rev. Letters 8, 142 (1962).

Brookhaven to verify this hypothesis. Formulae were set up that will allow a comparison. At present it has been verified that the single-pion contribution to np charge exchange is zero in the forward direction, when the single-pion exchange contribution is treated as an analytic continuation in angular momentum. Therefore it is expected that the ρ meson will give the dominant contribution to the high-energy np charge exchange. (Ivan J. Muzinich)

PLASMA PHYSICS

General Studies

The problem of nonlinear hydrodynamic instability was approached from the point of view of exchange of energy between Fourier components of the flow. Simple situations have been treated in this manner by J. T. Stuart. An attempt to extend this method to several fluids in contact was made, and is still in progress. (Maurice Neuman)

With the aim of calculating the contribution to the thermodynamic functions of a quantum plasma from binary collisions (i. e., two-body scattering under an effective potential including the polarization of the medium), a direct calculation of these effects in terms of the interaction coupling constant (e^2) expansion was tried and found impractical. Upon investigating an expansion about the classical limit (in powers of $\hbar^2$), a method of evaluation of the scattering contribution was found. Further, a general development of many-body perturbation theory in a functional integral expression for the partition function was derived and applied to the problem. This expression yielded a simple form for an expansion in powers of $\hbar^2$ about the classical limit including or excluding any desired orders of the perturbation series in powers of e^2. The work has not yet been published. (Sidney Putnam)

The method of Kaufman and Watson,[1] in the theory of the polarization of an imperfect gas, has been extended to obtain an expression for the dependence of the polarization on the cube of the field strength. This result was achieved by summing a group of terms proportional to E^3 in the perturbation series for the polarization. (Louis T. Klauder, Jr.)

The general theory and proofs of the invariance to lowest order of the adiabatic invariant series for charged-particle motion have been given.[2] An attempt to obtain the second correction to the magnetic moment was abandoned in the face of extensive algebraic calculations. (Theodore G. Northrop)

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

[2] Theodore G. Northrop, The Adiabatic Motion of Charged Particles in Electromagnetic Fields, UCRL-9517, Jan. 1961.

A study of the kinetic equations for a plasma (following the work of Harris, Rosenbluth, Rostoker, and Simon) was initiated, with the purpose of determining the importance of cooperative effects. Work is still in progress. (Theodore G. Northrop)

An expansion similar to that of Kruskal[3] was obtained for the non-relativistic motion of a charged particle in electric and magnetic fields varying slowly in space, with the classical radiation reaction force on the particle included. It was shown that the modification of the usual drift expression due to radiation reaction is smaller than the rate of decay of the Larmore orbit due to the particle's radiation. A quantity was obtained which is an adiabatic invariant in the special case in which $\vec{E}$ and $\vec{E}\cdot(\vec{\nabla} \times \vec{B})$ are small (that is, proportional to the smallness parameter). In the limit of small radiation effects, this quantity approaches the magnetic moment of particle. (David L. Sachs)

Stability Studies

R. W. Bussard's work on the stability of steady hydromagnetic flows[4] was reviewed. The double variational principle $\propto$ minimax > 0 for stability (< 0 for instability) was found to fail for the hydrodynamic Helmholtz instability of two compressible fluids of equal density. Bussard's generalized eigenvalue equation has been solved for this case and the (formal) reason for the breakdown of the theory clarified. The relation of Bussard's stability criterion to the sufficient conditions of Frieman and Rotenberg[5] was also considered. This work has been described elsewhere.[6] Various cases of the hydromagnetic Helmholtz problem, including compressibility, are currently being considered. (Alan B. Macmahon)

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[3] M. Kruskal, Gyration of a Charged Particle, PM-5-33 NYO-7903, 1958.

[4] R. W. Bussard, An Energy Principle for the Stability of Hydromagnetic Plasmas in Equilibrium Motion, LAMS-2534, May 23, 1961.

[5] E. Frieman and Manuel Rotenberg, Revs. Modern Phys. 32, 898 (1960).

[6] Alan B. Macmahon, Stability of Steady Hydromagnetic Flows, in Controlled Thermonuclear Research Semiannual Report, UCRL-9969, Jan. 1962.

An investigation of the stability of a mirror machine with conducting end plates was made by means of the Matterhorn energy principle. The conducting end plates were introduced to eliminate the flute instability. A perturbation expansion in $\beta(P/B^2)$ and in the curvature of the lines of force was made to simplify the calculation. Unfortunately, this approach did not yield any new information. It was necessary to consider the case of finite β and finite curvature to obtain significant results. Under these assumptions a nonlinear partial differential equation was obtained, but not solved. (Shalom Fisher)

The effect of "finite" ion Larmore radius is considered in relation to the Helmholtz instability. In this approach terms of the order ω/Ω_i, ω/Ω_e, ka_i, and ka_e are set much less than one. Terms of the order $(ka_i)^2\ \Omega_i/\omega$ are considered to be of order unity. However, terms of the order $(ka_e)^2\ \Omega_e/\omega$ are set much less than one, which amounts to considering the ion Larmore radius large compared with the electron Larmor radius. The physical effect of this approximation is to alleviate or cancel the flute instability. Here Ω is the cyclotron frequency, a is the gyro-radius, k is the wave number of the perturbation, and ω is the growth rate of the instability. The subscript "i" refers to ions, the subscript "e" to electrons. The Helmholtz instability is being analyzed by means of the Vlasov equation and Maxwell's equations. A study of small oscillations about equilibrium yields a dispersion relation between k and ω and furnishes the conditions for instability. (Shalom Fisher)

Ion Magnetron Experiment

An experiment to determine the electrostatic potential distribution in the Berkeley ion magnetron has been analyzed. Requirements on the performance of the experiment, as well as a model for interpretation of the results of the experiment, have been given. This work is described in a separate report.[7] (Theodore G. Northrop)

[7] Theodore G. Northrop, A Proposed Experiment to Measure the Radial Electric Field Distribution in Crossed-Field Discharges, UCID-1372, June 1961.

ATOMIC PHYSICS

The Goldstone many-body perturbation theory[1] was applied to the calculation of corrections to the Hartree-Fock method for atoms, and the correlation energy among the 1s and 2s electrons in boron was calculated. The intermediate (excited) states in the perturbation theory were estimated by using a screened Coulomb potential and solving the Schrödinger equation on the IBM 709 computer. Though the 1s correlations agree well the those reported by Linderberg and Shull,[2] calculation of the 2s electron correlations gave very poor results. This is believed to be due to the approximation of the Hartree-Fock potential by a screened Coulomb potential, therefore a computational program was undertaken to calculate positive-energy Hartree-Fock states. Tentative calculations of the 2s correlations agree well with experimental evidence. The work is being continued with a calculation of the correlations among all electrons in the beryllium atom, using exact Hartree-Fock excited states in the perturbation calculation. (Hugh S. Kelly)

Some effects of electron correlations on the low-energy photoionization cross section of neon was investigated. The Hamiltonian used consists of the kinetic energy, the Hartree potential, and selected Coulomb interactions corresponding to the "Random-Phase Approximation" as developed by Sawada for the infinite electron gas,[3] and Takagi,[2] among many others, for nuclear structure.[4] At present, the generation of the wave functions and the evaluation of the necessary Coulomb matrix elements is almost completed, and numerical results are expected soon. (Philip L. Altick)

The wave function and phase shifts for an electron elastically scattered by a neutral hydrogen atom were studied by means of variational techniques. The investigation is continuing, with the problem currently programmed for numerical solution of the angular momentum states $\ell = 1$ through 6. (Robert L. Armstead)

The method of closely coupled optical potentials was applied to electron-hydrogen scattering at low energies. The method and related variational corrections are described in a published paper.[5] The investigation is continuing with computational studies in which the 1s, 2s, and 2p states are closely coupled and antisymmetrized. (Robert T. Pu)

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[1] Goldstone, Jr., Proc. Roy. Soc. (London) 239A, 26 8 (1957).

[2] Linderberg and Shull, J. Mol. Spectroscopy 5, 1 (1960)

[3] Katuro Sawada, Phys. Rev. 106, 372 (1957).

[4] Shuji Takagi, Progr. Theoret. Phys. (Kyoto) 21, 174 (1959).

[5] M. Mittleman and R. Pu, Phys. Rev. 126, 370 (1962).

The investigation of the scattering of electrons by atomic hydrogen, in collaboration with Harry M. Schey of LRL Livermore, was continued. An IBM 709 code was completed and elastic cross sections for energies less than the first atomic excitation threshold were obtained.[6] An investigation was also carried out of spin polarization and spin correlation effects in elastic electron—hydrogen atom scattering.[7] Work was started on the collisional excitation of hydrogen atoms by electrons, and finally preliminary work was started in collaboration with Kenneth Smith of Argonne National Laboratory for a review article on electron and positron hydrogen atom scattering.[8] (Philip G. Burke)

PARTICLE ACCELERATORS

Several-Hundred-BeV Accelerator

In connection with the Laboratory's interest in a new accelerator of the alternating-gradient type in the energy range of several hundred BeV, an informal planning group was set up, including individuals from several departments. Tentative parameter lists were established and preliminary work began on a variety of special problems. These included survey and alignment techniques, site and organization studies, rf system, injection schemes, and experimental facilities. With regard to injection it was decided to investigate in detail the use of a linear accelerator for several BeV, and work was initiated on beam dynamics as well as mechanical and electrical problems. The conclusion was reached that such a synchrotron and injector are indeed technically feasible. The principal effort should now be applied to detailed optimization of parameters for the purpose of establishing reliable estimates of costs, manpower requirements, and time schedules. The work of the planning group is documented by a special series of "Accelerator Planning Group" reports, available through the Information Division.

Since such an installation would certainly require a larger commitment in money and manpower than any existing project in high-energy physics, it is more important than ever to develop a sound basis for judging the usefulness of such a machine. As a first step in this direction, a summer study was organized to review the present state of theory and experiment and to consider the implications of an extension in accelerator energy by an order of magnitude. A number of experts from this country and Europe were invited to participate in the study, which lasted from the middle of June to the middle of August. Particular emphasis in the study here was on theoretical matters, following an understanding with Brookhaven that their August study of a possible international accelerator would concentrate most heavily on machine design and

[6] P. G. Burke, V. M. Burke, and H. M. Schey, Boulder Conference Report. Session I (W. A. Benjamin Inc., N. Y.) 1961; Scattering of Electrons by Atomic Hydrogen; Kenneth Smith and P. G. Burke, ibid., Elastic Scattering of Electrons from the 1S State of Atomic Hydrogen; also P. G. Burke and H. M. Schey, Elastic Scattering of Low-Energy Electrons by Atomic Hydrogen, Phys. Rev., April 1962.

[7] P. G. Burke and H. M. Schey, Polarization and Correlation Tensors in Electron Hydrogen Atom Scattering (paper presented at Mexico City meeting of American Physical Society, June 1961); P. B. Burke and H. M. Schey, Polarization and Correlation of Electron Spin in Low-Energy Elastic Electron-Hydrogen Collision, Phys. Rev., April 1962.

[8] P. G. Burke and Kenneth Smith, The Low-Energy Scattering of Electrons and Positrons by Hydrogen Atoms, Revs. Modern Phys., July 1962.

experimental questions. The seminar notes and reports arising from the Berkeley Study are to appear in a single volume. (Lloyd Smith)

Design studies of the magnets for a large-size alternate-gradient synchotron were initiated. A digital computer program for computing magnetic fields was started. (Hartland S. Snyder)

The problem of an injector was attacked by studying the focusing and other problems of a proton linac having an energy of the order of 3 BeV. Work is in progress. (Hartland S. Snyder)

Bevatron

The digital computer calculations on the external beam of the Bevatron were brought to a close. The problem consisted in the optimal determination of many parameters relating to the target, the two bending magnets, and the two quadrupole magnets being used in the system. A beam at the exit port of minimal size and rate of divergence in both the radial and the vertical planes was desired, along with minimized dispersive effects. The parameters chosen will yield a beam at 6.2 BeV of approximately 2.0 inches radial spread (including dispersion), a maximum radial divergence of ±4.5 milliradians, and approximately a factor-of-two increase in radial phase area due to dispersive effects. The beam will have a vertical spread of 0.5 inch and a maximum vertical divergence of ±4.0 milliradians. An acceptable beam at 4.2 BeV will also be obtained. (Philip F. Meads, Jr.)

The dependence of Bevatron acceptance at injection, and rf capture, on a number of parameters was studied. These parameters included the rate of rise of magnetic field; thickness and location of inflector septum; the distribution in radius, radial angle, and energy of the injected beam; the frequency of the radial betatron oscillations; and the equilibrium phase angle of the radiofrequency accelerating system. The work was an extension of that performed at Saclay and Harwell for the accelerators Saturne and Nimrod, respectively. The resulting equations were programmed for the IBM 709 by Herman Grunder of Mechanical Engineering. It is intended to use them to optimize the acceptance and capture at the new injection energy and to define the properties of the ion optical system between the new linac and the inflector. Valuable advice was given by Lloyd Smith. Work on this problem is continuing. (David L. Judd)

A calculation was made to explain the mechanism of beam spill by a thread target. The mechanism is thought to consist primarily of excitation of radial or phase oscillations by multiple scattering or energy loss, respectively, in the threads. Which of these two effects dominates depends on the parameters of the system. This work is described in a separate report.[1] (Alper A. Garren)

[1] A. Garren, Long-Spill String Target, BEV-646, June 8, 1961.

An IBM 709 Code (SPRAY) was written to estimate the distribution of protons scattered onto the Bevatron chamber walls by an internal target. (Alper A. Garren)

88-Inch Cyclotron

An extensive program of measurements and calculations was carried out on the magnetic field of the 88-inch cyclotron. This included measurements of the uncorrected field, calculations of the necessary currents in the pole-face windings to make the field suitable for acceleration, and remeasurement of the field with the pole-face windings so activated. This program was carried out at various excitations of the magnet. The main purposes of this program were to determine whether the cyclotron magnet was satisfactory (it was), and to obtain "catalogue" information on which to base calculations for setting the cyclotron for any desired particle or energy. The calculations were assisted by Jonathan Young, Ardith Kenney, and Herman C. Owens. (Alper A. Garren)

Calculations necessary for the design of the electrostatic deflector were completed. They were assisted by Jonathan Young, Ardith Kenney, and Herman C. Owens. (Alper A. Garren)

Miscellaneous

A study of the geometrical and "chromatic" aberrations of arrays of quadrupole magnetic lenses arranged to focus beams of charged particles has been initiated. It is hoped to enumerate the possible types of envelopes of particle trajectories near foci and to prepare a generalized computer program that will calculate and present in usable form those properties of the envelopes which are of interest in particular applications. At the same time, tolerance requirements will be found on errors of construction, excitation, and alignment of the quadrupole elements such that the basic aberrations, and not these errors, limit the optical quality of the system. (David L. Judd and Philip Meads, Jr.)

A program of study was conducted concerning desirable orbit and magnet properties of versatile AGS accelerators of very modest size intended for use with a hilac injector capable of supplying a variety of heavy ions; the AGS machines considered would accelerate these ions to energies in the range of a few hundred MeV per nucleon. Some considerations for small AGS machines turn out to a quite different from those for very high energies. Limitations on the maximum length of long straight sections were studied in some detail. Various magnet geometries were considered, and an approach to the high-efficiency extraction of primary beams was detailed. A number of other features were studied. This work was conducted in connection with an electrical, mechanical, and plant engineering study of possible future biomedical accelerators, in collaboration with Herman Grunder of mechanical engineering. Very useful contributions were also made by Hartland Snyder. (David L. Judd)

NUCLEAR PHYSICS

Fission

Quantative results on the properties of certain unstable equilibrium configurations of distorted nuclei, idealized as uniformly charged drops, was obtained with the aid of an IBM 704 computer. (Work with Stephen Cohen.) A systematic survey of these "saddle-point shapes," their moments of inertia, quadrupole moments, and energies is being prepared. The survey is aimed at covering the conditions prevailing throughout the periodic table of elements, i.e., for "fissionability parameters" from zero to one. (Wladyslaw Swiatecki)

Some progress was made in understanding the role played by the zero-point oscillations of a liquid surface in the theory of the surface energy of the liquid. A formula for the energy per unit area resulting from summing the zero-point energies up to a given cutoff wavelength was derived, but the fundamental problem of removing the arbitrary cutoff by relating it to the spacings and motions of the particles constituting the liquid has not been solved. (This work was done with J. Linhard, Aarhus University, Denmark, during a trip to attend conferences in Manchester and Geneva.) (Wladyslaw J. Swiatecki)

The first part of the analysis of the time-of-flight experiment on fission fragments and neutrons from Cf^{252} has been prepared for publication.[1] (Work with Stanley G. Thompson, Harry Bowman, and Doug Milton, Lawrence Radiation Laboratory, Chemistry.) (Wladyslaw J. Swiatecki)

A model was studied in which a fissioning nucleus is represented by two overlapping symmetric spheroidal drops of uniformly charged incompressible liquid. There was derived, by use of an unpublished approximate method due to J. A. Wheeler, an expression for the kinetic energy of the nucleus as a function of the two coordinates specifying the system and their time derivatives. A map of the potential energy of deformation is currently being prepared. To integrate the classical equations of motion for the fissioning nucleus and separating fission fragments, an IBM 7090 Fortran program is being written. Several phenomena, including the distribution of the kinetic energy of fission fragments and the number of neutrons released in fission, will be studied within the framework of the above model. (Wladyslaw J. Swiatecki and James R. Nix)

Collective Motion

The effect of ellipsoidal nuclear deformation in odd-mass nuclei on the rotational band structure, the magnetic moment, and electric-quadrupole reduced transition probabilities was studied. Also studied was the relationship

[1] 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}, Phys. Rev. (to be published).

between the rotational bands of an ellipsoidally deformed nucleus and the vibrational and rotational bands of a spheroidally deformed nucleus with γ-vibration rotation interaction in the limit of γ approaching 0 or $\pi/3$. Equations for the asymmetric rotor motion were derived. By using T. D. Newton's single-particle eigenvalues and eigenvectors, numerical calculations were performed showing rotational spectra associated with an odd nucleon (N=2 and N=4) in an ellipsoidal well. Numerical results are discussed in terms of the β and γ deformation parameters required to give the known spins of the odd-A cesium isotopes Cs^{127} to Cs^{137}. The rotational energy spectrum, magnetic moment of ground state, and various E2 transition probabilities were calculated for Cs^{131} for several deformations, with best energy-spectrum fit at $\beta = 0.28$, $\gamma = 38^{o}$. (Lucy Wu Person)

MISCELLANEOUS STUDIES

The theory of final-state interactions first developed by Watson[1] was extended through incorporation of recent developments in the study of analytic properties of wave functions[2] and scattering amplitudes. Techniques for describing the enhancement effect of multiple simultaneous final-state interactions were developed. They are now being applied to the process $p + d \rightarrow He^3 + n + \pi$,[3] and to the process $\pi^{\mp} p \rightarrow m + \pi^{+} + \pi^{-}$. (J. Gillespie)

Further work was done on a project for elucidation of the various transition processes which a μ meson makes after having been captured in a solid. The specific case investigated is lithium. The theory of Auger transitions involving the core electrons and the meson was improved, and ideas to improve the theory of Auger transitions involving the conduction electrons and the meson are still being investigated. Programs for use on the IBM-704 were completed and checked for accuracy. These have been used to obtain many of the energy levels, wave functions, and matrix elements needed in the problem, and it is expected that this will lead to an elucidation of the history of a μ meson caught in a solid. (Coates R. Johnson)

An attempt to make a Lamb-shift type of quantum electrodynamical correction to energy levels in a strong Coulomb field was continued. A closed form for the relativistic Coulomb-Green's function has not been found, so an effort was made to use the well-known expansion of the electron propagator in an external field in terms of the radial Green's function plus an expansion in angular momentum eigenstates. This method has been applied to the Lamb shift of tightly bound electrons in the ground state by Brown, Langer, and Schaefer.[4] It is hoped that a similar method may also be used with the

[1] K. M. Watson, Phys. Rev. 88, 1163 (1952).

[2] R. G. Newton, Rev. Math. Phys. 1, 319 (1960).

[3] A. Abashian, N. E. Booth, and K. M. Crowe, Phys. Rev. Letters 7, 35 (1961).

[4] G. E. Brown, J. A. Langer, and G. W. Schaefer, Proc. Roy. Soc. (London) A 251, 92 (1959).

functionally more complicated higher energy levels to give the energy of the electron in the presence of the external field and permit a check of the experimental work of Schacklett and Dumond.[5] (Michael Austin)

Work was continued on the theoretical framework for extracting information about the nuclear-pair correlation function from a careful measurement of the photoproduction of neutral pions from complex nuclei. It is expected that a report on this subject will appear soon. (Robert H. Traxler)

Consideration has been given to some phenomena of wave coherence in the scattering of particles by particles. Two specific phenomena have been considered:

a. In conventional scattering experiments the incident particle is correctly represented by a plane wave. If it were possible to arrange that (for example) the incident wave be a converging spherical wave, more detailed information concerning the scattering interaction might be obtained. Such an incident wave might be realized by imbedding the scatterer in a suitable medium.

b. Autocorrelation and cross-correlation techniques developed for astronomical studies of stars might be applied to the detection of scattered particles. Solid-state counters would seem to permit detection at several closely spaced points in space. By suitably correlating observations by these detectors the properties of the scatterer may be resolved.

An article on the detection of nuclear explosions has been written with R. Latter and R. F. Herbst.[6] In this article techniques for detecting explosions underground, in the atmosphere, and in space are studied. (Kenneth M. Watson)

A preliminary consideration of the rate of rise of "bubbles" or "fingers" in the late stage of Taylor instability has been started. It is hoped to obtain some insight into the influence of continuous density gradients, finite compressibility, etc., on this rate. (David L. Judd)

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[5] Robert L. Shocklett and Jesse W. M. DuMond, Phys. Rev. 106, 501 (1957).

[6] K. M. Watson, R. Latter, and R. F. Herbst, Ann. Rev. Nuclear Science, 11, 371 (1961).

MATHEMATICS AND COMPUTING GROUP

Kent Curtis

During the period covered by this report, the Mathematics and Computing Group has been engaged in work as outlined below.

Hydrogen Bubble Chamber Data Analysis

Programming was done for the Alvarez Physics Group data-processing system as follows.

PANAL

A program, PANAL, for editing data from the Franckenstein measuring projectors was written, code-checked, and released for production.[1] This program was written to (a) provide fast return on those events that were being rejected early in the analysis for reasons such as Franckenstein operator errors, Franckenstein hardware malfunctions, and paper tape converter errors; (b) accomplish some of the additional computing required to process three-view unlabeled track measurements from the automatic 72-inch measuring projectors; (c) reduce data from different measuring projectors to one standard format; and (d) originate a raw-data library of ordered events for input to the program PACKAGE described later in this report.

This program was written for the IBM 709 and 7090 and operates in three phases.

Phase 1

Subroutines are provided to handle data originating on cards (measuring projectors MPIA and MPIB) or paper tape (MPIIA, MPIIB, MPIIC, and MPIID).[2]

The raw data are subjected to rigorous tests for consistency and completeness. Some of the tests are:

1. Are the indicative data complete?
2. Were the correct fiducial marks measured?
3. Was each track measured in the correct number of views?
4. Is the apparent track image monotonic and continuous?

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[1] For a detailed description of PANAL, see Alvarez Physics Note No. 358.

[2] Programming is in progress to provide necessary handling routines for the magnetic tape system which will replace the paper tape output on the MPII machines.

An attempt is made to associate unlabeled track images in three views in the data originating from MPIIC and MPIID. Charged tracks which participate in two vertices are sought out and appropriately flagged.

From the three-view images of each track, the best two views are picked for subsequent analysis. This choice is made on the basis of the direction of the track with respect to the three possible stereo directions. Stereo consideration may still necessitate discarding some measurements at the ends of these chosen track image pairs.

Phase 2

The data are then organized into a standard format and written in binary form on magnetic tape with one event per record. Events that fail the tests in Phase 1 are included on the output tape in a record containing only the indicative data and reason for failure. The events on the output tape are then numerically ordered with respect to the indicative data. If Phase 3 is not used, a summary printer tape is prepared listing indicative data on all events processed and including appropriate comments on those events which failed the tests.

Phase 3

Two or more Phase 2 tapes may be merged and a summary printer tape of the results prepared.

PACKAGE

The space geometry programs PANG 15 and PANG 72 and the kinematics analysis program KICK were revised and combined into one program, PACKAGE.[3] This was done in order to combine the two geometry programs for easier maintenance, eliminate the intermediate PANG-to-KICK tapes, and include necessary revisions and new techniques for processing three-view unlabeled track measurements from the automatic measuring projectors MPIIC and MPIID.

The input for this program is the one-event-per-record binary tape from PANAL. Chamber-dependent parameters and choices of event types to control the analysis sections are introduced as initial conditions in the program. An experiment-dependent subroutine selects proper optical and magnetic field parameters as determined by the indicative data on each event.

The geometric reconstruction of PANG was split into mass-independent and mass-dependent subroutines. A section was added for the construction of apparent neutral vertex connectors which are no longer measured on MPIIC and MPIID.

[3] The programs PANG and KICK have been included in previous reports. Only additions and modifications are reported here. KICK is described in Reference Manual for KICK IBM Program, UCRL-9099, May 1961. A detailed description of PACKAGE is being written.

A topological event-type routine and a superior mass assignment scheme were written for assigning the proper "labels" (that is, track numbers) and, hence, correct mass hypotheses to unlabeled tracks from MPIIC and MPIID. This labeling is accomplished by making use of the track spatial curvature as calculated in the mass-independent subroutine and probing the encoded topological event type. Large errors in the calculated track curvatures are taken into account in the labeling technique.

Sections for updating information on whether or not a track appears to stop in the chamber and for making a test on how much of the chamber volume is illuminated were included.

Modifications to PANG and KICK were made to provide direct data transmission between them as subsections of PACKAGE.

This program is currently being used for Alvarez Group data analysis.

LINGO

This program maintains complete event-processing histories for the Alvarez Group data-processing system.[4] The volume of data being analyzed for present-day high-energy physics experiments introduces many data-processing problems similar to those encountered in inventory control. The use of techniques involving hand-prepared lists inevitably leads to chaos. A high-speed digital computer, on the other hand, does not suffer from fatigue and is admirably suited for handling large volumes of routine data. The program LINGO was written in order to use the IBM 7090 for the Alvarez Group's data-inventory problem.

As the name implies, this program has its own language by means of which a physicist may instruct the computer to perform a variety of inventory and event-history jobs. The internal processing subroutines are completely general. The various input sections, however, were written for the current K^- experiment. Hence, some revisions may be necessary for adaptation to a different experiment.

The program contains a set of general master indexing routines called LIBRARY CONTROL. LIBRARY CONTROL is responsible for maintaining a control index (master list) of all events in a given experiment. This index is a record of all scanning information on each event and will be continuously updated as new events are found in the course of scanning the film. A history of all measurements and kinematics analyses is also kept in the master list for every event in the experiment.

Using the LINGO language, the physicist is able to request that any definable subset of events in his experiment be processed. Upon receiving such requests, LIBRARY CONTROL will produce measurement control cards and listings for those events and will note the request in the master list.

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[4]The design study for the data library system LINGO was included in a previous semiannual report, UCRL-9704, May 1961, p. 30.

When the analysis of this subset of events is complete, LIBRARY CONTROL will record that fact along with some information on the result of the processing in the master list. At the same time it will update a physics data summary file (separate from the master list) with the pertinent physics quantities from the kinematics analysis. This data summary file is designed to serve as input to more specialized EXAMIN routines.

In addition to controlling the data-processing flow for an experiment, LIBRARY CONTROL is also capable of producing listings and tallies of definable subsets of events upon request. This too is done via the LINGO language.

EXAMIN

During this period the EXAMIN system was used to interpret event hypotheses for all Alvarez experiments now being analyzed.[5]

A concept (new to the EXAMIN system) of data summary tapes was conceived and programs written. This collection of programs is called SUMMEX. These programs permit one to drastically reduce the volume of output data currently required from PACKAGE. To accomplish this, those calculated quantities which are most often needed during post-PACKAGE processing are assembled in a readily accessible form on library tapes. Data from these summary tapes can be recalled by the library program LINGO for interpretation by EXAMIN routines.

SMP (Scanning-Measuring Projector)

Programming was initiated in connection with a new measuring projector being designed and constructed at LRL for the Alvarez Group. This projector allows film to be scanned and measured on the same machine. The measurements are fed into the computer by means of a direct data connection.

A program SMP1 provides for the direct data communication, reconstructs the coordinates of measured tracks, and displays these points, using the cathode-ray tube.

Several programs were written in connection with feasibility studies and noise filtering.

Effort is being made to develop a complete data-analysis system making use of the SMP.

ORBIT

This series of programs is now complete.[6] Given the initial conditions for momentum vector, mass, and range, this program will produce x, y, and z coordinates defining the orbit of a particle in a magnetic field. Effects of energy loss and multiple Coulomb scattering in hydrogen are included as perturbation.

[5] EXAMIN system itself was reported previously (see UCRL-9704, p. 30).

[6] ORBIT was reported previously. Additions and completion are reported here.

Finally, the space points are reprojected onto three planes of an actual bubble chamber camera system. These images are further subjected to simulated measurement errors.

Miscellaneous

A library system of limited scope was written for the associated-production experiment. This was a temporary measure until the general library system LINGO was completed.

The phase-space programs reported earlier were extended to include three-body and six-body calculations. Also, effects of resonances between pairs of particles were added.

The input-output sections of several IBM 704 programs were revised to permit these programs to be run on the IBM 709. Among these were data-file editing routines used in conjection with 15-inch bubble chamber experiments.

This work was done by Benjamin Abington, Silverio Almeida, J. Campbell, Lynn Champomier, B. Cottrell, Cecil Draper, Robert Harvey, Marcus Horovitz, Daphne Innes, David Johnson, Alice McMullen, Samuel Penny, Thomas Schneider, J. Stedman, Cecil Tate, L. Watkins, and Hovan Zarian.

A particle-interaction-simulation program called FAKE has been designed for the 7090. This program generates events similar to those observed in bubble chambers and puts data in a form acceptable to the Bubble Chamber Data-Processing Programs. Considerable effort was spent on determining phase-space weights for events involving more than three produced particles.

It is expected that this program will be used to study sources of error and bias in the analysis of bubble chamber experiments. (Grove Nooney for Alvarez Group)

Miscellaneous Mathematical and Programming Work

A new version of the program TAPER was written for the Nuclear Chemistry Group to provide buffered reading and processing of data tapes recorded by the pulse-height analyzer when used in a four-dimensional manner. Assistance was given to the Nuclear Chemistry Group in solving other computational and mathematical problems of a less complex nature.

A paper was prepared on a magnetohydrodynamics problem for presentation at the winter meeting in November of the American Society of Mechanical Engineers.[7] (Paul Concus)

[7] Paul Concus, Effects of a Magnetic Field on Natural Convection in a Toroidal Channel, J. Appl. Mech. (to be published).

Work was continued on a 709 program which will calculate the double spectral function of a set of coupled integral equations. The equations result from applying unitarity considerations to the Mandelstam representation of the scattering amplitude (direct and exchange) arising from a potential expressed by a superposition of Yukawa potentials. (Edwin Towster for John Charap)

A program was written for the IBM 709 to evaluate multiple integrals arising in the theory of π-n scattering. (Marjory Simmons for Bhal Udgaonkar)

Several additions and revisions were made to a program which calculates dispersion relations for torsional hydromagnetic waves in a plasma. These were written for the IBM 709 in connection with Hot House I and II. (Marjory Simmons for Alan de Silva)

A program was written for the IBM 709 to abstract information from a tape prepared by the program KICK IV. Then further programs were written to make histograms of various combinations of quantities on the abstract tape. (Marjory Simmons for Sula Goldhaber and Gerson Goldhaber)

A program to calculate bremsstrahlung cross sections was written for the 709. (David Stevens for Donald McPherson)

A 650 program to calculate all roots (real and complex) of any polynomial of degree 2, 3, or 4 with real coefficients was written. (David Stevens for Harry Heckman)

A 650 program to calculate AEC budget information was written. (David Stevens for George Pappas)

Work has begun on a program to calculate medical parameters from data obtained following injection of radioisotopes. This is being written in Fortran for the 7090. (David Stevens for Myron Pollycove)

Work has begun on an accounting routine to permit calculation of time records and statistics on computer utilization. This program is being written for the 1401. (David Stevens for James Baker and Kent Curtis)

A Fortran code to be used in computing equilibrium shapes of charged liquid drops was written. (Victor Brady for Wladyslaw Swiatecki)

The initial version of a Fortran code to be used in computing bound states of the molecular ions He^3H^+, He^4H^+, He^3D^+, He^4D^+, He^3T^+, and He^4T^+ was completed. (Victor Brady for John Hiskes)

The 650 program, ETHELBERT, was used extensively to compute particle orbits for setting up experiments at the Bevatron. (Victor Brady for the Alvarez Group)

A program was written for the 650 to (a) form all sums of pairs of numbers from a given list and (b) punch a table of differences of numbers in the list. These sums are compared with the numbers of the original list to see if any of the sums are equal to any of the numbers. (James Eusebio for William Kelley)

A program was written for the 650 to compute a convolution integral. (James Eusebio for Tin Maung)

A program was written for the 709 which specializes a function-minimization routine (ZO EO ZO13, variable metric minimization) to a least-squares fitting routine, by specifying that the function to be minimized be the error function of a least-squares fit (sum of squares of residuals). (James Eusebio for Harold Hanerfeld and Kent Curtis)

A program was written for the 709 to convert certain experimental data into a form suitable for input to a SHARE sorting program (IB9SRT). (James Eusebio for Hans Kruger)

Additions and revisions to a package of 7090 data-reduction programs were written in connection with experiments on K mesons in a xenon bubble chamber. The principal addition to the package is TAUFOR, written in order to identify τ^1 events among the $4\gamma - K^+$ decays and to calculate relevant kinematical quantities. (William Benson for John Brown, George Trilling, John Kadyk, and Remy Van de Walle)

A 650 program to compute integer roots of 3-by-3 matrices was written. (William Benson for Roger Wallace)

A 709 Fortran program to evaluate a function of several parameters for many different values of the parameter was written. (William Benson for Gabe Kajoian)

Two 709 programs to perform numerical integrations were written. (William Benson for Mel Bernstein and Remy Van de Walle)

A 704 program was written to fit, by least squares, experimental data to a given function of several variables. The functions given are eigenvalues which are computed by first evaluating the matrix elements as functions of the variables and then diagonalizing the matrix. The program is being debugged. (Thomas Clements for John Conway)

A 1401 accounting-type program has been written. This program tabulates the amounts of precious metals stored at various Laboratory sites. (Thomas Clements for Robert Strickland)

A program has been started to analyze particle behavior in a spectrometer. By a spectrometer, we mean an arbitrary sequence of quadrupoles, planes of counters, and field-free regions, followed by a circular deflection magnet (which also contains various counter planes), followed in turn by a final bank of counter planes. We consider an arbitrary window sequence--that is, sequence of square areas on the counter planes through which we require the particle to pass. For a fixed monoenergetic point source P the window sequence induces on the unit sphere centered at P a region R, which is the set of all points of intersection with the unit sphere of the paths of those particles which pass through all the windows. We calculate

(a) for given radial angle about the axis, the widest possible deflection from the axis with which a particle will pass through all the windows;

(b) the solid angle of R, that is, $\int_R dA/4\pi$; and

(c) the average distance, that is, $\int_R s\,dA / \int_R dA$;

where dA is an element of surface area and s is the total distance traveled by a particle passing through dA. Finally, we vary the energy of the particles from the monoenergetic point source P and graph the resulting values of solid angle and average distance. (Leslie Wilson for Hans Kruger)

A program has been written to do a complex-valued triple integration involving poles. (Leslie Wilson for James Ryan)

A 709 program, HYPERFINE, was written which makes a least-squares fit of a function (sum of exponentials) to decay data. The program corrects and normalizes the fitted function. The adjusted parameters are then fitted with a bell-shaped curve by a least-squares fit. The program was completed in August 1961. Modifications are now being incorporated which are primarily concerned with changing the form input-output and allowing for more flexibility in processing the data. (Barbara Steinberg for Howard Shugart)

A 709 program, SYNCH, was written which computes acceptance of a particle in a synchotron, at a point $P(\alpha, x)$, where α = initial angle upon entering the vacuum chamber, and x = initial radial coordinate. Three boundary conditions, which limit the acceptance, are considered. (Barbara Steinberg for Herman Grunder)

A subroutine, FANDOT, which performs various matrix operations on two matrices yielding a third matrix, was written for the 709. (Barbara Steinberg for John Howe)

A 704 program, CYBOUT, was written to perform calculations necessary for the design of the shape of the deflector channel for extracting the beam from the 88-inch cyclotron. Modifications were made to allow channel wall coordinates to be introduced directly as parameters. (Herman Owens for Alper Garren)

Analysis of measured field data for the 88-inch cyclotron to determine optimum trim-coil currents was continued. Work was begun on a formal report which contains detailed descriptions of the programs used.[8] (Ardith Kenney and Jonathan Young for Alper Garren)

A modification of a 704 Los Alamos program, WILD, was made to allow it to be run on the 709 computer. This program is used in the analysis of salary data. (Edna Williams for Paula Deluca)

A 709 Fortran program to integrate the dimensionless equations of motion for phase oscillations in an accelerator was written. (Edna Williams for Alper Garren)

All the data-processing routines used in the analysis of magnetic measurements by the Magnet Test Group were converted from the 650 to the 709. The existing data were converted from punched card to magnetic tape and processed with these new programs. This has greatly accelerated the processing of data.

In addition, work was started on studying ways of testing and correcting processed data. (Bert Albrecht for the Magnet Test Group)

Two programs for performing numerical integrations, one single integration and one double integration, were written for the 709. (Bert Albrecht and Klaus Halbach)

[8] Alper A. Garren, Jonothan Young, and Ardith Kenney, Computational Procedure in the Adjustment of a Cyclotron Magnetic Field by Trimming Coils, in Proceedings of an International Conference on Sector-Focused Cyclotrons (to be published in Nuclear Instr. and Methods).

A 709 program was written using the program VARMINT by David Stevens to fit various data from the π-π experiment of Auerbach, Johnson, and Lach.[9] One of the functions fitted was $F = X^A(b+cx+\cdots)$. An effort was made to fit to it efficiency curves for all the neutron counters. It was hoped that the need for large amounts of graphical input data to Johnson's Monte Carlo program for the cross sections could be obviated. However, the fit was not accurate enough in all cases and some graphical data will still have to be used. (Joe Good for William Johnson)

Data analysis (least-square fit, resolution, and phase-space folding) on data concerned with the π-π scattering length was done on the 709. (Joe Good for Norman Booth)

Work was begun on a $\bar{p}$-p phase-shift program for the 709. The differential cross section and polarization are calculated as a function of angle and energy by using partial waves up to f in the standard way. No pole contributions have been attempted. No attempt, as yet, has been made to reverse the procedure and fit the phase shifts. (Joe Good for Herbert Steiner)

Modifications to the RECOIL[10] programs were made to permit processing of specially exposed emulsions. (Carl Quong for Richard Lehman)

A preliminary study to determine the feasibility of Monte Carlo methods in counter design was made. Because of the nonlinearity of the variables, it was concluded that other methods would be used. (Carl Quong for Edward Pullen)

A Monte Carlo program, KETHY, has been written for the purpose of calculating the complete decay configuration of a K^+ meson decaying into π^0, e^+, and ν particles. This was done for the IBM 709. (Carl Quong for John Kadyk)

A program for calculating the angular distribution of the intensity of light scattered from a uniformly illuminated spherical bubble was written for the 709. (Carl Quong for John Brown)

Using a Los Alamos program which solves the nonlinear least-squares problem by Gauss's Method, an IBM 704 subroutine was written to describe a three-temperature evaporation formula. This function defines the neutron density as a function of the lab velocity of the neutrons and the lab-system

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[9] The reactions studied were $\pi + p \rightarrow p + \pi + \pi$ and $p + p \rightarrow p + n + \pi$.

[10] Described in Physics Division Semiannual Report, UCRL-9704, May 1961, p. 36.

angle between the neutron and the light fragments. Successful runs were made with up to eight fitting parameters using 465 input points from an experiment on neutron emission in the spontaneous fission of Cf^{252}.[11] (Claudette Rugge for Harry Bowman)

A function subroutine was written on the IBM 709 to evaluate the mass of a nucleus as a function of the mass number, using Seeger's semi-empirical atomic mass law.[12] (Claudette Rugge for Douglas Milton)

A Fortran subroutine for computing a definite integral by Simpson's Rule was submitted to the IBM 709 library. By use of a recurrence formula, successive approximations are made until the absolute percentage error between two of them is less than a preassigned value, or until a preassigned maximum number of iterations has taken place. (Claudette Rugge for Harold Hanerfeld and Kent Curtis)

An IBM 709 Fortran program was written to read the binary output tape of TAPER IV and form sums of corresponding elements of any number of specific 100 × 100 matrices found on the tape. The program prints out this sum in one 100 × 100 array, and it will repeat this process any number of times for a fixed input tape. (Claudette Rugge for Richard Chanda)

Modifications were made in a Monte Carlo event-generating program[13] to permit further comparisons with data. (Gordon Sutherland for John Kadyk)

A program was written for the 709 to perform matrix operations and calculations required in a study of deformed nuclei.[14] (Gordon Sutherland for Sven Nilsson)

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[11] 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.

[12] Philip A. Seeger, Semiempirical Atomic Mass Law, Nuclear Physics 25, 1 (1961).

[13] John A. Kadyk, Generation of Three-Body Production and Decay Processes Following Phase-Space Distribution by Monte Carlo Method, UCRL-9614, April 1961.

[14] S. G. Nilsson, J. Sawicki, and N. K. Glendenning, The Giant El Resonance for Deformed Nuclei, UCRL-9803, Sept. 1961.

Computer Operations and Systems Programming

Operations

During this interval, an IBM 1401 computer was installed in Building 46 and a Type 717 printer and Type 714 card-to-tape converter were released. The 1401 assumed a very large proportion of the off-line printing and card-to-tape and tape-to-card conversion functions in the Computer Center. An IBM 7090 computer was installed in Building 50-Increment II on October 1, 1961. During this interval, the Computer Operations staff was enlarged sufficiently to permit the operation of both the 7090 and 709 computers. More efficient systems for handling the flow of problems through the Computer Center were installed.

Systems Programming

Major systems-programming effort during this interval was devoted to the preparation of systems for the 1401 and 7090 computers. A comprehensive printing and conversion system which is described below was written for the 1401 computer. The Fortran monitor system was modified to allow the free interchange of programs between the 709 and 7090 computers. Revisions were made in both the Fortran and SOS monitor systems to allow the use of an on-line clock and interval timer on the 7090. Routine maintenance of the Fortran and SOS systems also continued during this period.

Initial design studies were made for a multiprogramming executive system which will be required during the coming year as a result of the increasing use of scanning and measuring equipment operating on line with the 709 and 7090 computers. It is hoped that during the next interval design specifications will be completed for this executive system and that a preliminary version of the system will be made operational. (James Baker)

The basic processing programs for the IBM 1401 have been written. The purpose of these programs is to facilitate the rapid flow of information to and from the IBM 709 and 7090. These programs transfer data from punched cards to magnetic tape, from magnetic tape to punched cards, and from magnetic tape to printer. Other programs available for use are a card reproducer, a 1401 symbolic assembler package, and a 1401 core dump. (Walter Hutchinson for James Baker and Kent Curtis)

Future Plans

Plans were made for the installation of a second 1401 system in Building 50-Increment II to be delivered in early January of 1962. This is required in order to handle the printing requirements arising from the use of the 7090 computer and to allow more time for administrative data-processing functions on the 1401. In addition, plans for the installation of a paper tape reader on the present 1401 were made. This is expected in November or December 1961.

Investigation was begun as to the best means of meeting three expected requirements. The first of these is the requirement for more flexible and accurate means of obtaining graphical display from computers. Specifications have been drawn up and discussed with several manufacturers. Proposals are expected in the near future.

A second requirement is for additional printing capacity which will be needed by June or July 1962. Several methods of meeting this need are being considered.

The third requirement is for increased computing capacity during 1962, and a still further increase during 1963. Arrangements are being made with the Campus Computing Center to enable us to use a 7090 which they expect to install in July 1962. In order to satisfy additional requirements expected in 1963 inquiries are being made to all manufacturers of computers concerning suitability and availability of machines. These studies are expected to require several months, but it is hoped that conclusions can be drawn by Spring of 1962.

The increased use of computers for analysis of data from on-line measuring machines and the availability of new types of computer equipment and input-output equipment has made it both necessary and desirable to investigate new ways of using computers. Techniques making it possible for several levels of data processing and problem solving to occur simultaneously are being studied. Some of the objectives are: (a) to allow on-line measuring apparatus to be used simultaneously with processing of unrelated program; (b) to make possible on-line debugging of programs without sacrificing machine efficiency; (c) to allow a scientist to interact directly with the computer to solve complex problems.

Work has begun on this research program; the executive routine being prepared by James Baker (see above) is the first step in this process. (Kent Curtis)

Part B: November 1961 through April 1962

No report covering this period had been received at the time of publication, but it is expected that the work will be described in the next semiannual report.

PHYSICS RESEARCH

Edward J. Lofgren in Charge

K^+ - PROTON INTERACTIONS

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

The large-angle elastic scattering of K^+ mesons by protons has been studied at 970 MeV/c, 1170 MeV/c, and 1970 MeV/c by surrounding a liquid hydrogen target with rectangular spark chambers. The forward scattering has been studied with a scintillation-counter hodoscope.

The results of experiments at lower energies have shown the angular distributions to be isotropic. This experiment, however, shows an anisotropy in angular distribution that increases with increasing energy. The total elastic cross section has been found to decrease with increasing energy, reaching a value of about 7 mb at 1970 MeV/c. A number of phase-shift solutions using $S_{1/2}$, $P_{1/2}$, and $P_{3/2}$ partial waves have been found at 970 and 1170 MeV/c. Those which give the most reasonable continuation from the lower-energy data show a falling S-wave phase shift and rising P-wave phase shifts. At present a phase-shift analysis that includes $D_{3/2}$ waves is being attempted. In this analysis all the absorption is assumed to take place in the $D_{3/2}$ state. The 1970-MeV/c distribution has been fitted by an optical model.

The present data have been included with other information on K-nucleon scattering in a test of the forward-scattering dispersion relations. An acceptable fit is found for small positive or negative values for the average pole term.

π^+ - PROTON ELASTIC SCATTERING AT 1.5, 2.0, AND 2.5 BeV/c

Victor Cook, Jr., Bruce Cork, and William R. Holley

Scanning of the spark chamber film (about 25,000 pictures), carried out independently at the University of Michigan under the direction of Martin L. Perl and at Berkeley, has been completed. The analysis of the data, including a comparison of the results of this experiment on π^+-p with other measurements of π^--p elastic scattering at the same momenta, is under way. The results are also being compared with the predictions of dispersion theory concerning a backward peak in π^+-p elastic scattering.

Preliminary results show clearly the effects of the 1450-MeV/c π^+-p resonance on elastic scattering. The π^+-p elastic scattering distribution at 1.5 BeV/c has a 1-mb/sr bump, which reaches a maximum near $\cos\theta = -0.4$, superimposed on a nonresonant background of about 0.4 mb/sr. The π^--p distribution has a similar but smaller backward bump, supporting the assignment of $T = 3/2$ to this resonance. At 2.0 and 2.5 BeV/c the π^+-p and π^--p distributions are very similar; both are dominated by large forward diffraction peaks which fall smoothly to a flat distribution in the backward hemisphere at about 0.1 mb/sr.

K^+ - NUCLEON INTERACTION—PION PRODUCTION BY K^+ MESONS ON HYDROGEN AND DEUTERIUM

Sulamith Goldhaber

The processes of single π-meson production by K^+ mesons on hydrogen and deuterium have been investigated by Sulamith Goldhaber in collaboration with members of the Segrè Group (William Chinowsky, Gerson Goldhaber, and Theodore F. Stubbs) and the UCLA Physics Department (J. Fisk, Harold K. Ticho, and Donald M. Stork). For this experiment pictures taken with the 15-inch bubble chamber were analyzed.

At incident momenta of 642 MeV/c and 810 MeV/c the total inelastic K^+-p cross sections are 0.06±0.03 and 0.95±0.16 mb respectively. The branching ratios at 810 MeV/c for reactions yielding $K^0p\pi^+$, $K^+p\pi^0$, and $K^+n\pi^+$ are 0.66±0.10, 0.23±0.05, and 0.11±0.05 respectively. The identifiable K^+ processes are those yielding $K^0p\pi^0$, $K^0n\pi^+$, and $K^+p\pi^-$. For these three reactions the cross section is 0.11±0.04 mb at 642 MeV/c and 1.06±0.11 mb at 810 MeV/c. At the higher momentum, the branching ratios are 0.23±0.14, 0.29±0.15, and 0.48±0.09.

In the distribution of K^0p effective mass we find a concentration of masses in the region between 1460 and 1500 MeV. In view of the known K^+-p elastic and K^+-n charge-exchange scattering cross sections, it appears difficult to attribute this peaking to a resonant K-nucleon interaction. In the $K^0\pi^+M^*$ distribution the high M^* values are enhanced.

Effective-mass distribution for pairs of particles in the state $K^+p\pi^-$ show no significant deviations from phase-space predictions. The angular distribution of the proton is sharply peaked in the backward direction while the K meson is forward peaked in the center of mass of the system. These results can be interpreted in terms of a "single-pion-exchange mechanism." With this model we calculate a $K^+\pi^-$ total scattering cross section assumed constant over the available range of $K^+\pi^-$ masses yielding $\sigma_{K\pi}$ of a few millibarns.

π-π INTERACTION STUDIES

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

Preparations continued for a Bevatron experiment scheduled to begin in May. The purpose of this experiment is to study the final-state correlations between pions in pion-nucleon interactions at high energies. It is hoped that it will be possible to look for π-π energy resonances, determine their spin, and investigate the Chew-Low extrapolation scheme at three incident π momenta (2, 3, and 4 MeV/c) with a large number of events at each energy.

In order to describe adequately the unstable "particles" produced, the invariant multipion mass, the momentum transfer, and the missing mass must be determined to within a fraction of the pion mass. Therefore, the

energy-momentum balance involving the incident pion and final-state particles must be accurately measured. To accomplish this, a large-aperture high-resolution magnetic spectrometer employing spark chambers coupled with a large bending magnet will be used.

K^- - PROTON INTERACTIONS

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

A cylindrical spark chamber array was used to examine the interactions of K^- mesons with protons at energies close to the 1-BeV/c K^--p resonance. Data have been taken at frequent intervals between 700 and 1400 MeV/c. A thin foil chamber was used to give accurate angular measurements and a large semicylindrical chamber containing graphite and steel to provide information on polarization and range. These data are being analyzed to obtain both elastic and inelastic cross sections and angular distributions.

BERKELEY LINEAR ELECTRON ACCELERATOR OPERATIONS

William L. Everette

The Berkeley electron linac continued its services to research programs in the areas of chemistry, physics, and soils and plant sciences. These programs were mentioned in the report for the period May—October, 1961 (UCRL-10113), and need not be elaborated upon here.

One additional program of considerable interest was initiated in January by Dr. Lionel Farber from the Sea Food Research Division of the Hooper Foundation in San Francisco. Dr. Farber's studies of the fish are centered on the bacteriological decay mechanisms of the raw fillet. His interest is to find a means of retarding this phenomenon and simultaneously preserve the nutritional value and piquant quality of the fish. Preliminary results reveal that freshly packaged fillet of sole when irradiated by electrons to 10^5 rad level within 24 hours of death is preserved 30 to 50% longer than fish in nonirradiated packages. Larger doses change the fish and the result is less palatable food.

Efficiency tests on cosmic ray particle detectors of the scintillator-photomultiplier type have been completed. These experiments were carried out in the gamma field resulting from 10^{10} to 10^{12} e^-/cm^2 bombarding a thick aluminum target. A decrease in efficiency as large as a factor of two has been observed. This fatiguing effect is thought to be due to secondary charge effects within the phototube. This work was conducted by Selig Kaplan and P. Ogden from the Moyer Research Group. The counters were intended for use in space vehicles.

Usage of the linac over this report period has been about the same as for the preceding period. Chemistry continues to be the larger consumer at about 35% total beam time. Physics ran second at 32%; Soil Sciences, 20%; and Sea Food Research and Special Applications, 12%. Total beam time for

the period ran 45%. Some machine modifications have been made. The Varian VA-820 C klystron, 5 MeV peak power, has been installed and is now functional, but the larger power drive source, a Raytheon Magnetron, has yet to be installed. The klystron requirement is about 60 watts. Only 30 watts are available from the present system, resulting in half-power operations. The present electron energy is only 8 MeV, but a factor of 3 in intensity has been gained. The new drive system should be installed by August 1, 1962, and full-energy operation of about 10 to 12 MeV should be possible.

Future work utilizing the linac in addition to be the previously mentioned programs will include electron spin resonances by Tom Gunter from Dr. Tobias's Group and radiation-induced electroluminescent studies by Health Physics; also--as soon as the 12-MeV energy level is reached--the measurements of partial polarization of bremsstrahlung from thin foils by use of photodisintegration of the deuteron and solid-state counters will be feasible.

PHYSICS RESEARCH

Burton J. Moyer and A. Carl Helmholz in charge

PHASE-SHIFT ANALYSIS IN π-p SCATTERING

Robert J. Cence, Paul M. McManigal, and Burton J. Moyer

A computer program has been written to determine the phase shifts in π-p scattering by the method of least squares. It will vary through G waves, both the real and imaginary parts of the phase shifts. This program began as an extension of the one written by Jim Foote in the Segrè group. However, in addition to variation of the imaginary parts of the phase shifts, other essential changes have been made. First, the dispersion theoretical calculation of the real part of the forward amplitude has been included as a piece of input data. Secondly, the grid method of varying the phase shifts is no longer used. Instead, the phase shifts are varied by a modified gradient method. In this method the gradient of χ^2 with respect to all the phase shifts that are varied is calculated. The χ^2 is calculated at three points along this gradient, and quadratic fit is made to three points. On the basis of this fit a minimum is predicted to which the program then moves all the phase shifts. The process is repeated until an absolute minimum is reached. We find that this method is four to five times as fast as the grid method. The program is now being modified to include isotopic spin analysis.

Our major interest is in the higher resonances in π-p scattering. We have begun an analysis of π^+-p and π^--p elastic scattering and polarization from recent experiments (described in the following sections).

Because it is clear that one must in some way extrapolate the phase shifts from lower energies, we intend to analyze again the phase shifts at all lower energies. The results of previous analyses are neither precise nor consistent enough for this kind of extrapolation.

NUCLEAR EXCITATION FROM μ^- CAPTURE

Jagdish Baijal, Justo Diaz, Donald E. Hagge, Selig N. Kaplan, and Robert V. Pyle

Nuclei excited by the capture of μ^- mesons de-excite principally by the emission of neutrons. The energy spectra of these neutrons have been measured for the elements Al, Fe, Ag, I, Au, and Pb.

The experiment was performed in the meson cave of the 184-inch cyclotron. The measurements were of knock-on proton pulse-height spectra in a 1-in.-thick liquid scintillator. The reduction to incident neutron spectra is now in progress. Measurements with D-T, Pu-Be, and mock fission sources indicate that good reproduction of incident-neutron spectra can be obtained from a first-collision theory with hydrogen alone (i.e., neglecting collisions with carbon).

The energy spectra, when analyzed in conjunction with previously measured neutron mutliplicities, will give the average nuclear excitation produced by μ^- capture and conceivably also some information on excitation distribution.

RADIATIVE CAPTURE OF NEGATIVE PIONS IN FLIGHT

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

The experiment to be performed at the 184-inch cyclotron will study the reaction $\pi^- + p \rightarrow \gamma + n$ and $\pi^- + p \rightarrow \pi^0 + n$; the π^0 from this latter reaction quickly decays into two γ rays. The experimental data will be of particular interest at low (but finite) pion energies for obtaining more information about S-wave pion parameters. Specifically, the first reaction plus a detailed balancing argument will be a measurement of the cross section for $\gamma + n \rightarrow \pi^- + p$.

The radiative reaction is experimentally distinguished from the charge-exchange reaction by measuring the energy of the γ ray with a total absorption scintillation gamma counter. This gamma counter has been described,[1] and has a measured resolution of ±6% at 129 MeV.

One run has been completed at the cyclotron; it served to measure the resolution of the gamma counter and point up several background problems. Another run is now under way with a different arrangement of counters to reduce the background problem; additional instrumentation has been assembled which will allow us to accurately measure the composition of the beam.

TEST OF ISOTOPIC SPIN CONSERVATION IN STRONG INTERACTIONS

John A. Poirier and Morris Pripstein

A sensitive test of I-spin conservation is to look for the reaction $d + d \rightarrow He^4 + \pi^0$, which is forbidden by this conservation law. This reaction was investigated at the Berkeley 184-inch cyclotron in the summer of 1960, and preliminary results were subsequently reported.[2] In recent months, a more comprehensive analysis of the data was initiated and is now virtually completed. On the basis of information derived from this analysis, an upper limit for the differential cross section for the reaction in the center-of-mass system at about $\theta_{cm} = 90$ deg has been re-evaluated and a value of 1.5×10^{-34} cm^2/sr is obtained. The data are consistent with no π^0 production.

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[1] William C. Bowman, Jim B. Carroll, and John A. Poirier, A Total-Absorption Scintillation Counter for High-Energy Photons, Rev. Sci. Instr. (to be published).

[2] John A. Poirier and Morris Pripstein, Phys. Rev. 122, 1917 (1961).

From a comparison of this upper limit with the theoretical prediction of the cross section for this reaction, if isotopic spin need not be conserved,[3] we conclude that isotopic spin is at least 99.6% conserved. A Ph. D. dissertation, based on this experiment, is being written by one of the experimenters (M. P.).

PION PRODUCTION BY PIONS INCIDENT ON PROTONS

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

The experiment to measure the distribution in energy and angle of the neutrons from the reactions

$$\pi^- + p \rightarrow \pi^+ + \pi^- + n$$
$$\rightarrow \pi^0 + \pi^0 + n$$

has been partially analyzed.

The total cross sections for the $\pi^0\pi^0 n$ mode are $\sigma = 0.8 \pm 0.2$ mb and $\sigma = 1.1 \pm 0.3$ mb for incident π^- energies of 380 and 430 MeV, respectively. Both of these values are considerably higher than the predicted values obtained from Schnitzer's scattering lengths, which fitted our previous results.

Another feature of the data is the strong enhancement over the phase-space distribution for the high values of $\omega_{\pi\pi}$ (the total energy in the two-pion system). Since it appears in both modes and is absent in the $\pi^-\pi^0 p$ final state, it is probably a $T = 0$ effect.

Analysis of our data for the low values of $\omega_{\pi\pi}$ close to the kinematic limit shows that an expected enhancement based on the results of Abashian, Booth, and Crowe on π production in $p + d$ collisions is not seen at the expected magnitude.

PION-PROTON SCATTERING AND POLARIZATION

Robert J. Cence, Thomas Devlin, Dale F. Dickinson, Richard D. Eandi,
Donald E. Hagge, Jerome A. Helland, Robert W. Kenney,
Paul G. McManigal, Burton J. Moyer, and Robert A. Profet

Our second major experiment in the study of the elastic scattering of positive and negative π mesons on protons in the region of the higher resonances was carried out at the Bevatron during this report period. The data are presently being analyzed.

The experimental setup performed in a highly satisfactory manner, and we encountered virtually no down time due to equipment failure throughout the entire experiment. The magnetic-core matrix for data storage and

[3] K. R. Greider, Phys. Rev. 122, 1919 (1961).

read-out directly onto IBM cards was found to be a useful system for this type of experiment, and it allowed us to perform preliminary data analysis while the experiment was in progress.

At present, the data have been analyzed for angular distributions. The few minor corrections that still have to be made are not expected to make any qualitative changes in the results. The normalization difficulties encountered in the previous $\pi^- + p$ scattering experiment were satisfactorily removed, and the present results are in substantial agreement with the results of that experiment, but now give dependable absolute cross-section values. The behavior of the angular distributions for $\pi^+ + p$ elastic scattering in the vicinity of 1200 to 1400 MeV is characteristic of strong enhancement of the cross section by one or two states of high angular momentum (probably F waves). A phase-shift analysis will be performed on the final results to attempt to determine which states are involved in the interaction.

In addition to the elastic-scattering experiment, a second concurrent experiment to study the polarization of the recoiling elastic protons was performed. Elastic events were identified by counters, and the protons were observed as they produced tracks in either one of two spark chambers with graphite plates. The asymmetry in proton-carbon scattering events in the chamber provides the basis for determining the polarization of the protons.

At present, about 30% of the film from the spark chambers has been scanned, and computer programs have been developed for the data analysis. Tentative results for the polarization of the recoil proton as a function of the pion scattering angle have been calculated for $\pi^- + p$ at 600 MeV with the statistical accuracy we expected to obtain when the experiment was designed. At the present rate, allowing for increased personnel and rescanning, the analysis should be completed in about 6 months. Mechanical methods for scanning the film are being studied.

NEUTRAL PIONS FROM PROTON-PROTON COLLISIONS AT 735 MeV

Robert J. Cence, Don L. Lind, Gilbert Mead, and Burton J. Moyer

Detailed analysis of the results of our investigation of the reaction $p + p \rightarrow p + p + \pi^0$ at 735 MeV has been completed.

Computer codes were used to make all necessary corrections to the data and determine the final spectra. The cross section for π^0 production was measured and found to be 3.46 ± 0.25 millibarns. By use of a least-squares analysis, momentum and angular distributions for the neutral pion were determined from the photon spectra, under the assumption that all the photons came from π^0 decay. The angular distribution is proportional to $1/3 + (0.24 \pm 0.03) \cos^2\theta_{cm}$.

There is evidence for photons arising from a source other than π^0 decay. These photons lie in the energy region from 145 to 230 MeV in the two-proton center-of-mass system. They represent approximately 2% of the total number of γ rays. We have been unable to find a reasonable explanation for these photons. A future run has been scheduled at the cyclotron in order to further investigate this phenomenon.

PHYSICS RESEARCH

William A. Nierenberg in charge

ATOMIC BEAM GROUP

Howard A. Shugart

The Atomic Beam Group continues to devote most of its effort to 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 β- and γ-ray spectroscopy.

Work published during the year 1961 describes measurements on the isotopes Sc^{46}, Ga^{68}, Ga^{70}, Rb^{85}-Rb^{86}, Y^{90}, Y^{91}, Ag^{112}, Ho^{161}, Lu^{177}, Au^{196m}, Bi^{210}, Pa^{233}, and Am^{242}. In addition to the measurement of new spins, hyperfine structures, and nuclear moments, several developments in atomic beam technique have been made. A new detection scheme was developed by Prof. Eugene D. Commins and David A. Dobson for use in an experiment to measure the nuclear magnetic moment of 18.5-sec Ne^{19}. In this experiment, neon atoms are produced continuously in the 60-inch cyclotron and transported through a tube to the atomic beam apparatus near by. A single deflecting field, which acts on the nuclear moment, separates the beam into two components. One of these beams is passed through a homogeneous transition field and into a storage bulb. The storage bulb has approx 100 cc volume and a small entrance slit. The polarized nuclei retain their polarization as they bounce around inside the detector. When the Ne^{19} nuclei decay, the emitted β^+ particles show an anisotropy along and opposed to the spin direction. This anisotropy can be used to determine the orientation of the spin after the particles have traversed the transition region. The apparatus has been constructed and beams with the expected anisotropy obtained.

Another interesting development has occurred. The largest spin ever directly measured (I = 12) has been found for Au^{196m} (10 hr) by Yau Wa Chan and Wesley B. Ewbank. The result was in slight disagreement with previous predictions and has stimulated a reinvestigation of the β- and γ-ray spectra of this isotope.

PHYSICS RESEARCH

Wilson M. Powell and Robert W. Birge in charge

BUBBLE CHAMBER OPERATIONS

The Weak Decays of Hyperons

Wilson M. Powell and William J. Singleton

The stopping K^- film is being scanned for the weak decays

$$\Lambda \rightarrow p + e^- + \bar{\nu}, \quad \text{(a)}$$

$$\Lambda \rightarrow p + \mu^- + \bar{\nu}, \quad \text{(b)}$$

$$\Sigma^\pm \rightarrow n + e^\pm + \nu, \quad \text{(c)}$$

$$\Sigma^\pm \rightarrow \Lambda + e^\pm + \nu. \quad \text{(d)}$$

The few examples of (a), (b), and (c) reported in the literature indicate the rates are lower by an order of magnitude than the predictions of the universal Fermi interaction.[1] No examples of (d) have been seen, and Okun[1] estimates a branching ratio of approximately 10^{-4}.

On the basis of a preliminary scan, 450,000 Λ's, 50,000 Σ^+, and 25,000 Σ^- were produced either by K^- interacting at rest or from interactions in flight (the K^- entered the chamber at 450 MeV/c). To date 72 examples of the electronic decay of the Λ have been tentatively identified, but no estimate of the branching ratio has been made. Groups from the University College, London, and the University of Colorado are participating in the scanning.

Bubble Density in Heavy-Liquid Bubble Chambers

Robert Ely, George Gidal, and Sedong Kim

Hahn has reported a relativistic rise in the bubble density in a freon bubble chamber of approximately 30% from minimum ionization ($\gamma = 6$) to $\gamma = 100$ for pions and protons.[2] We investigated this effect in a 74%/26% mixture (by weight) of freon (CF_3Br) and propane for electrons from γ-ray pairs and we found an average increase in bubble density of 25% over a range of γ from 50 to 750. The measurements were made both by bubble counting on scan tables and by constructing integral gap-length curves by use of a projection microscope. An automatic gap-length measuring apparatus has been constructed and preliminary results agree with hand measurements.

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[1] L. Okun, Strange Particles, Ann. Rev. Nuclear Sci. 9, 61 (1959).

[2] B. Hahn, in Proceedings of an International Conference on Instrumentation for High-Energy Physics, 1960 (Interscience Publishers, Inc., New York, 1961), p. 143.

π-π Interactions in 3-BeV π-Nucleon Interactions

Zaven Guiragossian, Robert W. Birge, Robert P. Ely,
George Gidal, Wilson M. Powell, and Howard S. White

The following abstract was submitted to the Washington meeting of the American Physical Society:

"We have used the LRL 72-inch hydrogen bubble chamber with a 3.0-BeV/c π^- beam to study inelastic π-p interactions. Events were analyzed through the FOG-CLOUDY-FAIR data-reduction system. We have identified 1200 events to be (1) $\pi^- + p \rightarrow \pi^- + \pi^0 + p$ (π^-, π^0 system; T=1, 2), or (2) $\pi^- + p \rightarrow \pi^- + \pi^+ + n$ (π^-, π^+ system; T=0, 1, 2). If high-energy interactions are dominated by a Regge pole having the quantum numbers of the vacuum (T=0, G=parity even), then such a particle should manifest itself in the physical region as a π - π resonance in the T=0, J=2 state, at s = 50; $s = \omega^2/\mu^2$, the π - π barycentric energy squared. Our distribution in s shows a resonance at s = 27 in Reactions (1) and (2). This is the T=1 ρ meson. Moreover, (2) shows a peak at s = 50, whereas (1) has no such peak."

Because the possible resonance at s = 50 discussed in the paper is important, and because the film from which data were taken was of poor quality (having been exposed during the first engineering run of the 72-inch hydrogen chamber), the data in this experiment were completely reviewed.

A new parameter characterizing the average of the four largest deviations of the measured points from the fitted curves was computed and carried through the FOG-CLOUDY-FAIR system to allow the separation of well-measured events. As expected, only about half of the data was satisfactory, but nonetheless the distribution in "s" of the remaining data showed the same features as before but with even less statistical significance. As a result, no conclusions can be drawn without further data. An attempt was made to obtain film from either Brookhaven or CERN, but without success, hence the answer may have to come from other research groups who do have comparable film.

During the investigations mentioned, the capacity of the new FAIR system for summarizing and making histograms of data was used continuously and most satisfactorily. Literally hundred of histograms with all possible variations of parameters were generated in our search for errors in the data.

π^+-p Scattering at 600 MeV

Peter Newcomb

The measurement and computer analysis of 2400 π^+-p interactions in the 15-inch hydrogen chamber have been completed. Bias corrections for the total cross sections and a phase-shift analysis are currently being made.

Polarization of the Neutron from Σ Decay

Robert W. Birge

An attempt is being made to measure the polarization of the neutron from Σ decay in the 72-inch hydrogen bubble chamber by looking at proton recoils in the liquid of the chamber. Because the decay modes $\Sigma^{\pm} \rightarrow n + \pi^{\pm}$ show no up-down asymmetry even when the Σ is known to be polarized, it is assumed that parity is conserved in the decays (whereas the decay mode $\Sigma^{+} \rightarrow p + \pi^{0}$ does not conserve parity) and the decays proceed to a pure s- or p-wave state. The purpose of the experiment is to determine which state is associated with each decay mode.

To date, 381 Σ^{+} events from $\pi^{+} + p$ interactions at 1170 MeV/c have been measured and processed. The program has computed the direction of the neutron, and scanning will now be carried out to find proton recoils.

Because these events overlap those used by Gerald Smith and Fernand Grard, we have been able to make a detailed comparison of the results of the FOG-CLOUDY-FAIR computing system (and measurements) with the PANG-KICK-EXAMIN system. The comparison showed excellent agreement.

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DATA ANALYSIS

Howard S. White

Operation of FOG-CLOUDY-FAIR Data Processing

Howard S. White

During the period of this report, FOG programs processed more events than were measured, so that by April all the backlog of unprocessed events was cleared. The number of events measured for the several current experiments is shown in Table I.

A total of 32,816 origins was processed through the FOG program system. Of these, 19,805 were processed by use of Program 119, which allowed automatic assignment of mass and sign of charge for the tracks, so that standard event-type calculations were used. For the remaining 13,011 events, the more flexible option of describing each event independently by mass code on a track-by-track basis was elected. This technique eliminates many kinematic fits which would be indistinguishable from other mass assignments, and thus inserts into the kinematical analysis the scanner's knowledge of particle identification as deduced from ionization.

Table I. Experimental results processed by FOG programs

Experiment number	Beam	Bubble chamber	Vertices measured
16	1.15-BeV/c K^-	30-inch propane	6,643
19	3.02-BeV/c π^-	72-inch hydrogen	1,683
20	750-MeV/c K^+	30-inch propane	3,053
21, 22	750-MeV/c π^+	15-inch hydrogen	1,102
23	500-MeV/c K^-	30-inch propane (propane-freon)	8,539
24	1.17-BeV/c π^-	72-inch hydrogen	1,317
25	3.02-BeV/c π^-	72-inch hydrogen	1,098

The CLOUDY system processed 48,400 chains of unrelated vertices during the period of this report. This number is substantially larger than the number of events processed by FOG, and indicates that--since events are frequently useful for more than one physics purpose--substantial saving of additional measurement and data handling is achieved by having the processing of an event-type-independent form on the FOG library.

Routine production of the FAIR system was achieved during this period. A total of 44,649 chains of unrelated vertices was summarized from 12 different physics experiments.

FOG-CLOUDY-FAIR Program Development

Howard S. White and Dennis Hall

The FOG program system was reassembled with several modifications and additions. The major changes were to consolidate space-reconstruction programs for two-,three-, and four-view input into one package. Extensions were also made in the ability to recognize and overcome computer errors during processing runs. Because of interest in the use of this program system at other laboratories, a small effort was expended in adapting the system to chamber configurations different from Berkeley's. This adaptation consisted chiefly of setting program parameters to appropriate values, but also required generalization of the magnetic-field expressions contained within the program. Small groups of data from the Brookhaven National Laboratory 20-inch hydrogen chamber, the CERN 30-cm hydrogen chamber, and the Ecole Polytechnique 100-cm propane-freon chamber have been processed. The results have been satisfactorily compared to results obtained from other reduction systems.

The FOG program is now being modified to operate in a multiprogrammed manner in conjunction with the Flying-Spot Digitizer system.

The CLOUDY program system now consists of two programs. One of them (Program 208) searches FOG library for events of similar type and initiates CLOUDY libraries for these events. This program is capable of handling a variety of topological configurations as well as different kinematic events in a simultaneous data mix. The kinematics program has been modified to best use the flexibility of data arrangement allowed by Program 208. It now has the ability to perform simultaneous multivertex constraints where the vertices are connected by either charged or neutral tracks. Additional work was done to improve the analytic treatment of constraints involving tracks stopping in the chamber.

The ability of the FAIR program systems was improved by insertion of a number of new subroutines into the system package. These routines allow us to systematically make a number of specialized calculations on specific groups of data. Such calculations, which are distinguished by being pertinent to one group of events, are more suitably done in the FAIR system than in CLOUDY, since the function of CLOUDY is to provide standard calculations for all events. Work progressed on the sections of FAIR output programs that produce weighted histograms and scatter diagrams.

The basic design of the FSD program (HAZE), including real time and multiprogram use of the computer, had been established by the beginning of the period of this report. Detailed programming of the production system was begun in November and by May, gating, filtering, and control programs had been satisfactorily operated upon data contained in tapes generated by the prototype FSD located in CERN. The operational program also includes the logic for communication with the FSD, the ability to search for FSD fiducials without knowledge of the film position, and the ability to output the measurements in a form acceptable to the FCF system. This program is now operational and will be used with the FSD to debug real-time relationships involved in the system.

An additional program for the FSD system has been written to sort the scan-table measurements and edit them for use by the FSD program. This input editing program also produces a daily scanning summary which will be used to provide immediate summarization of scanning efforts in conjunction with the FSD scanning system. Such quantities as total volume of data, number and kind of errors, scanner's efficiency, and specific scanning rates will be routinely provided in a daily report form. Completion of this program is expected during June, in time for use with the first FSD scan table.

Some effort was devoted to planning for the advent of new computer hardware to be attached to the 7090. Additional attention was given to a variety of large-scale computers that are now being considered by LRL so that the growth of executive programs suitable for concurrent supervision of several FCF programs might be channeled in a direction appropriate to the greatest variety of possible future hardware.

Flying-Spot Digitizer Development

Howard S. White and Jack V. Franck

Detailed design and fabrication of the components for the FSD were largely completed during this period. The FSD minimum system was operated in March. This minimum system was sufficient to digitize actual bubble chamber film and to transmit the two-dimensional coordinates through electronic circuitry into a high-speed buffer memory and then to more slowly transmit these coordinates into the IBM 7090 memory. The purpose of the buffer, therefore, is to allow very short time separation between the consecutive digitizings of closely spaced tracks while metering out the coordinates at a rate suitable for input to the 7090. Thus the minimum system, comprising approximately 75% of the final hardware, has been tested. Design and installation of the remaining parts--including film transport, stage, servo, and control logic--is progressing. The final slit and disc assembly has been designed and is being fabricated. It is expected that all hardware will become operational in June.

Design and fabrication for the FSD scan table were begun in March. This scan table is to be based upon an LRL SP-IV, but will include the necessary digitizer for rough coordinates as well as sophisticated hardware designed to optimize the human operations associated with scanning and with the reduction of scanning records by computers.

In January, a conference was held at Berkeley for the discussion of Hough-Powell development. This was attended by representatives from CERN, Saclay, Harwell, Brookhaven, Argonne, and Berkeley. This meeting was the third of a series of informal meetings that have allowed the general interchange of ideas and philosophies for construction of FSD-type systems. It is from meetings of this kind that many of the principles of the FSD system have emerged. Discussions included progress reports, a critique of ideas concerning immediate plans for the first operational FSD system, and several proposals for extensions of FSD techniques into the area of automatic scanning and pattern recognition.

PHYSICS RESEARCH

Emilio Segrè and Owen Chamberlain in charge

SINGLE-MESON PRODUCTION IN $\pi + p$ COLLISIONS

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

We have continued the analysis of the reactions[1]

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

$$\pi^+ + p \rightarrow \pi^+ + \pi^+ + n \qquad (2)$$

at incident pion momentum of 1.75 BeV/c.

The experiment confirms the position and approximate width of the resonance in the two-pion system corresponding to the ρ meson (Fig. 1, a and b).

We have also analyzed the data for correlations in the two possible final-state pion-nucleon systems. Let $\omega_{\pi n}$ be the invariant total energy of the neutron and one of the final-state pions in their own barycentric frame. For each event we calculated $\omega_{\pi 1}$ and $\omega_{\pi 2 n}$. Since we cannot distinguish the charge of the final-state pions, each event was plotted twice to give the histogram $d\sigma/d(\omega_{\pi n})$ of Fig. 1 c. This distribution shows a marked peaking in the vicinity of the (3/2-3/2) and (1/2-5/2) pion-nucleon resonances, and may indicate that the difficulties encountered in the extrapolation method are due to pion-nucleon interactions.

Recently Yang and Treiman[2] have proposed a method of testing the validity of the one-pion exchange model. In the rest frame of the incident pion, the distribution of the plane defined by the final-state pion momenta $\vec{p}_{\pi 1}$ and $\vec{p}_{\pi 2}$ must be isotopic about $\vec{q} = \vec{p}_n - \vec{p}_p$ if a single pion is exchanged. Our $\pi^-\pi^+$ data show a marked anisotropy for the highest momenta measured. For lower-momentum transfers, the distribution appears flat within the statistics. For the $\pi^+\pi^+$ system, the anisotropy is less pronounced and may not be statistically significant. These anisotropies indicate that the high-momentum measurements should not be interpreted as solely due to one-pion exchange.

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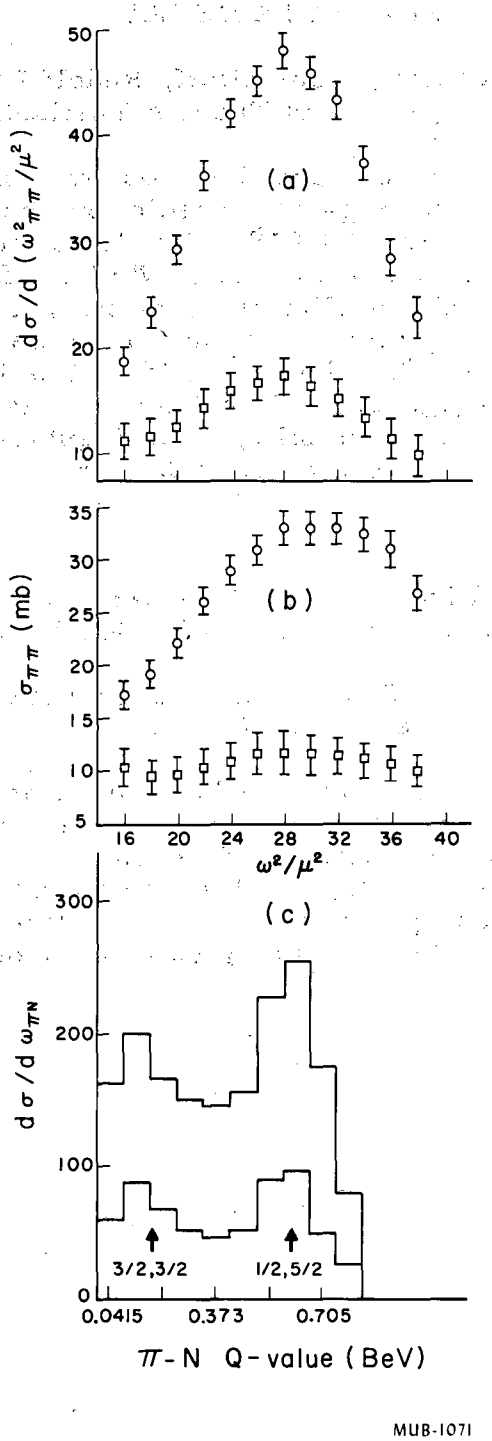

Fig. 1. The differential cross section $d\sigma/d(\omega^2/\mu^2)$ as a function of ω in BeV. (b) $\sigma_{\pi\pi}$ as obtained by integration over p^2 in the physical region. In (a) and (b), the upper curve is for Reaction (1) and the lower curve is for Reaction (2). (c) The distribution $N(\omega_{\pi n})$ as a function of the Q value in the pion-nucleon system. The positions of the 3/2, 3/2 and 1/2, 5/2 pion-nucleon resonances are indicated by arrows.

PION BETA DECAY

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

We have stopped 4.5×10^{10} positive pions to look for the decay $\pi^+ \rightarrow \pi^0 + e^+ + \nu$. The branching-ratio prediction, based on the conserved vector current hypothesis, is 1.0×10^{-8}. Our detection efficiency is about 0.003, and we therefore expect 1.5 events. We have found two possible events. The detector is an array of scintillation counters that identify and time (a) the stopping pion, (b) the π^0 gamma rays, (c) the emission of the e^+, and (d) the annihilation of the e^+. Though the identification appears to be so restrictive as to be unambiguous, it is not impossible that the events are accidental. Allowing for the possibility of accidentals, we can say that it is 90% probable that the branching ratio is $\leq 3\times10^{-8}$. The experiment is still in progress.

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

Norman E. Booth, Roger Hill, Norman H. Lipman, Hugo R. Rugge,
and Olav T. Vik

A preliminary measurement has been made of the polarization of the neutron from the reaction $\pi^- + p \rightarrow \pi^0 + n$ at an incident pion energy of 310 MeV. The pion beam was obtained from the 184-inch cyclotron and impinged on a liquid hydrogen target. Liquid helium was used to analyze the polarization of neutrons produced at a barycentric angle of 30°. An improved liquid helium analyzer is being built for another run in July.

PHYSICS RESEARCH

George H. Trilling and Gerson Goldhaber in charge

This Group began its official operation on April 1, 1962. There is little, therefore, to report in the way of results obtained between April 1 and April 30, 1962. During that period, considerable effort was devoted to preparations for an experiment to be run at Brookhaven in collaboration with William Chinowsky of the Segrè Group. This experiment consists of a study of the interactions of 2-BeV/c K^+ mesons with hydrogen, carried out by means of the BNL 20-inch hydrogen bubble chamber.

Descriptions of the work of Gerson Goldhaber, Sulamith Goldhaber, W. Lee, and collaborators during the period up to April 1 appear in the report of the Lofgren Group. Below we briefly describe the work of members of what was the Glaser Group prior to the formation of the Trilling-Goldhaber Group.

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 angular correlations and energy distributions in the decay $K^+_{e3} \rightarrow e^+ + \pi^0 + \nu$ were carried out in film taken with a xenon bubble chamber exposed to a separated stopping K^+ beam. It has been shown that the data are in excellent agreement with the V-A theory and would be difficult to reconcile with other couplings. Limits have been set to the energy dependence of form factors relevant to the K^+_{e3} decay.

Studies of the $K^+_{\mu 3} \rightarrow \mu^+ + \pi^0 + \nu$ decay mode have also been carried out. It has been found, by comparison with the K^+_{e3} results, that the data agree well with the hypothesis of μ-e universality. Numerical values of appropriate form factors have been obtained.

Study 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)

A precise measurement of the branching ratio,

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

is being made by means of a study of the decays of K^0 mesons produced by charge exchange of K^+ mesons in a xenon bubble chamber. We have obtained a preliminary value, $B_K = 0.329 \pm .013$, which agrees very closely with the prediction of the $|\vec{\Delta T}|^K = 1/2$ selection rule. Final corrections to this answer are now being made.

High-Field Bubble Chamber

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

Design work for a proposed 40-kgauss propane-freon bubble chamber is being carried out in collaboration with members of the Engineering Department. The feasibility of this project hinges on the continued success of developments in the area of superconducting magnets.

PAPER ISSUED

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^+_{e3} Decay Interaction, Phys. Rev. Letters 7, 423 (1961).

ACCELERATOR OPERATION AND DEVELOPMENT

BEVATRON

Edward J. Lofgren in charge

The report for August through October 1961 has been issued as "Bevatron Operation and Development. XXXI," UCRL-10122, May 1962.

184-INCH CYCLOTRON

Robert L. Thornton in charge

Reported by James T. Vale

The 184-inch cyclotron was used for research experiments approximately 85.5% of the time that the crew was on duty during this period. The largest amount of outage was caused by the shutdown in November 1961, which used about 9% of the total time for this period.

The shutdown was scheduled primarily for three jobs:

(a) vacuum-pump relocation,

(b) installation of an improved magnet-cooling-oil pump,

(c) connection of the new cooling tower into the water system.

The vacuum pumps had to be moved to get them out of the way of the new building annex.

New oil-cooling pumps of higher capacity were installed in the magnet-cooling system. This system now keeps the oil temperature at a lower, and thus safer, point.

Additional cooling capacity has been needed for the 184-inch area because of the expansion of this area and the increased complexity of experiments. A second cooling tower was constructed and connected to the existing water-distribution systems at this time.

Building Addition

The increased complexity of the research experiments conducted on the 184-inch cyclotron has meant that more space is needed for efficient work. In addition, experiments will become possible that, owing to space limitations, are not feasible now. Therefore, construction of an addition of about 8000 square feet to the cyclotron building was started in January 1962 and is scheduled to be finished in October 1962.

Auxiliary Dee

The auxiliary dee for beam duty-cycle improvement has been in operation long enough for evaluation of its performance. It is an extremely valuable addition to the cyclotron, since it allows practically all research experiments to be operated at maximum beam intensity thanks to the reduction of background. It has proved to be a fairly reliable and consistent device in the past few months, but improvements are still planned to make it more reliable and less tricky to operate. Operation with 50% efficiency is now quite standard, and peaks of 60% have been recorded.

Tank Activity

During the first part of May, it was necessary to enter the cyclotron tank to repair the dummy dee structure. Preceding the entry, operation was limited to low-level alpha beam for two days to keep the tank radioactivity to a minimum. The tank was entered 2 hours after beam shutoff, and at that time the activity in the center of the machine was 4 roentgens per hour and at the 81-inch radius point was 16 r/h. Eight hours after the shutdown the activities were 2 r/h at the center and 8 r/h at the 81-inch point. Twenty-four hours later the activities were essentially unchanged. Samples of material from inside the tank were obtained and analyzed, with preliminary results as follows:

Copper produced	Co^{58},
Brass produced	Co^{58} and Zn^{65},
Iron produced	Mn^{54},
Stainless steel produced	Mn^{54}.

Wade Patterson of the Health Physics Department is conducting the analyses and will report in full when they are complete.

This is a critical problem common to all accelerators, since it is obvious that a person can get an exposure of 1 roentgen for a few minutes' work in the machine. The problem is much more critical, of course, in accelerators that have higher beam intensities than the 1-μA beam current in the 184-inch cyclotron.

88-INCH CYCLOTRON

Elmer L. Kelly in charge

Work done at the 88-inch cyclotron was described in a number of reports presented at a conference on sector-focused cyclotrons, April 17-20, 1962, at University of California at Los Angeles, to be published in Nuclear Instruments and Methods.

60-INCH CYCLOTRON

W. B. Jones in charge

OPERATION

Summary of Usage

Summary of usage as prepared by Peter McWalters for this 6-month period:

Alpha bombardments	1485.8 hr
Deuteron bombardments	383.5 hr
Proton bombardments	773.4 hr
Experimental bombardments	170.7 hr
Operations total	2813.4 hr
Outage	363.4 hr
Available time	3176.8 hr
Shutdown	951.2 hr
Holiday	216.0 hr
Total time	4344.0 hr

An operating efficiency of 88.5% was maintained throughout this 6-month period.

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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