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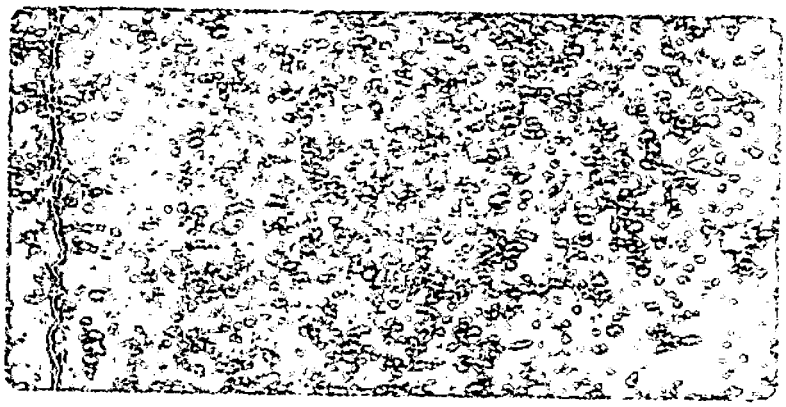

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UCRL-20120
UC-34 Physics
TID-4500 (56th Ed.)

PHYSICS REPORT

November 1969
through
June 1970

David L. Judd
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LAWRENCE RADIATION LABORATORY
University of California
Berkeley, California

PHYSICS REPORT

November 1969 through June 1970

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Physics Research

THEORETICAL PHYSICS

Geoffrey F. Chew, Group Leader

I. HIGH-ENERGY PHYSICS

CHARGED PION PHOTOPRODUCTION

J. D. Jackson and C. Quigg

The work on charged pion photoproduction at high energies, using finite energy sum rules to construct a pseudomodel on the one hand, and a phenomenological model with Regge poles plus absorptive cuts on the other, was completed and written up for publication. The main extensions of the previous work were the demonstration that the pseudomodel gives a fit to the high-energy observables over a range of momentum transfers considerably beyond the region of the sharp forward peak, namely for $0 < -t < 0.5\ (\mathrm{GeV}/c)^2$, and the calculation of the asymmetry from a polarized target in terms of the parameters of the pion pole and a natural parity Regge exchange (A_2). The recently published results on the asymmetry from a polarized target select one set of Regge parameters which, for the A_2 pole, are consistent with the requirements of factorization implied by purely hadronic processes. The paper, "Remarks on Pion Photoproduction," is to be published in Nuclear Physics B in the near future.

FINITE-ENERGY SUM RULES, DUALITY DIAGRAMS, AND HYPERON POLARIZATION IN THE REACTION $K^-n \to \pi^-\Lambda$

R. D. Field, Jr. and J. D. Jackson

We are in the process of completing a finite-energy sum rule evaluation of the Regge pole amplitudes in the reaction $K^-n \to \pi^-\Lambda$. This study was motivated by the failure of duality diagrams to predict the observed nonvanishing lambda polarization for near-forward scattering in $K^-n \to \pi^-\Lambda$. Using a narrow resonance approximation for the low-energy amplitudes, we are investigating the status of exchange degeneracy of the K^* and K^{**} trajectories.

Assuming that only the K^* and K^{**} trajectories contribute, we are able, with a suitable choice of resonance parameters, to find two solutions. One solution fits the observables for $K^-n \to \pi^-\Lambda$ at $p_{lab} \approx 4.5$ GeV/c, but is unable to predict correctly the observables for the line reversed reaction $\pi^+n \to K^+\Lambda$ at this momentum. The second solution predicts $\pi^+n \to K^+\Lambda$ correctly at $p_{lab} \approx 4.5$ GeV/c, but as before is unable to predict the line reversed reaction correctly. The problem stems from the fact that at $p_{lab} \approx 4.5$ GeV/c the differential cross section for $\pi^+n \to K^+\Lambda$ seems to have a slope approximately one-half that of the line reversed reaction $K^-n \to \pi^-\Lambda$, whereas the above two solutions predict the same slope for the two reactions. Recent experiments indicate, however, that at higher energies ($p_{lab} \approx 10$ GeV/c) the slope of the differential cross sections for $K^-n \to \pi^-\Lambda$ approaches the slope of $\pi^+n \to K^+\Lambda$ as predicted by our solutions. This suggests that when

$p_{lab} \approx 4.5$ GeV/c the energy may not be high enough to allow neglect of the background term or that there are Regge cut terms present which die away as the energy increases.

DIFFERENTIAL AMPLITUDES IN PHOTOPRODUCTION

Harald J. W. Müller*

Recently Fubini et al.[1] and Rebbi[2] suggested a differential approach to the kinematics of particle reactions. The approach was motivated by the observation that particles with spin lead to partial-wave decompositions of the scattering amplitude involving derivatives of Legendre polynomials. By a suitable construction of invariants, however, new amplitudes may be defined which possess simple scalar-like partial-wave expansions.

The differential approach has been applied to the t-channel kinematics of charged pion photoproduction and the connection between the differential amplitudes and customary CGLN, Ball, and helicity amplitudes has been worked out. Further studies are planned exploring the usefulness of the differential approach in various problems.

*NATO Fellow.

1. S. Fubini, in Proceedings of High Energy Physics Conference, Heidelberg, 1967, p. 644; and V. DeAlfaro, S. Fubini, C. Rossetti, and G. Furland, Ann. Phys. (N. Y.) 44, 165 (1967).
2. C. Rebbi, Ann. Phys. (N. Y.) 49, 106 (1968).

BOOTSTRAP CALCULATIONS OF $\pi\pi$ SCATTERING USING THE MANDELSTAM ITERATION

Bryan R. Webber

Some strip-model calculations of $\pi\pi$ scattering have been performed. In these calculations, unitarity was imposed by means of the Mandelstam iteration.[1] This procedure has the advantage that the output trajectories and residues (including their imaginary parts) may be computed above as well as below threshold; this is at present not feasible in calculations using the N/D technique.[2]

First, a bootstrap calculation of the ρ trajectory was carried out, neglecting Pomeranchuk exchange. The extra requirement of self-consistency above threshold is very strict, but a solution with satisfactory consistency in the range -1 to +2 $(\text{GeV})^2$ was obtained. The scale of energy was established by giving the ρ resonance the physical mass; the self-consistent ρ width was then 400 MeV. Various dynamical approximations were investigated, and it was shown explicitly that the pion mass is not a significant parameter of the dynamics.

Finally, a bootstrap calculation of both the ρ and Pomeranchuk trajectories was performed. Except for the value of the Pomeranchuk residue above 0.5 $(\text{GeV})^2$, the results showed satisfactory self-consistency between -1 and +2 $(\text{GeV})^2$. The self-consistent Pomeranchuk trajectory had an intercept $\alpha_P(0) \approx 1$ and a slope $\alpha'_P(0) \approx 0.5\,(\text{GeV})^{-2}$. The inclusion of Pomeranchuk exchange did increase the slope of the ρ trajectory, but the effect of this on the ρ resonance width was offset by a more rapid increase in the imaginary part of the trajectory, and the self-consistent ρ width was about 600 MeV. It is conjectured that the more encouraging results of including Pomeranchuk exchange in other calculations[3,4] were due to defects of the N/D technique,[5] and that the ρ is in fact primarily a bound state of some channel other than $\pi\pi$.

1. S. Mandelstam, Phys. Rev. 112, 1344(1958).
2. G. F. Chew and S. Mandelstam, Phys. Rev. 119, 467 (1960).
3. P. D. B. Collins and R. C. Johnson, Phys. Rev. 182, 1755 (1969).
4. R. C. Johnson and P. D. B. Collins, Phys. Rev. 185, 2020 (1969).
5. D. H. Lyth, On the Collins-Johnson Bootstrap Calculation of the J = 1 $\pi\pi$ Scattering Amplitude, CERN TH-1143, March 1970.

THE SCHIZOPHRENIC POMERANCHUK AND THE STRIP MODEL

Cristian Sorensen

Collins and Johnson[1] have been able to obtain an apparently[2] successful bootstrap of the rho (ρ) and the Pomeranchuk (P) trajectories by using a strip approximation to the $\pi\pi$ scattering amplitude. The J-plane structure of their isospin-zero amplitude is, however, not rich enough. They do not have any singularity that could be interpreted as the P' of phenomenological analyses. Recent work on multiperipheral models,[3,4] which have a very similar physical content, suggests that: (i) the low-energy component of the multiperipheral kernel generates a single isospin-zero pole similar to the one obtained by Collins and Johnson; (ii) the high-energy tail of the kernel complicates this simple J-plane structure and the resulting singularities can be interpreted as the phenomenological P and P'.

Given the strong parallelism between the two models mentioned above, it has been conjectured[3] that the removal of a certain cutoff, which effectively suppresses the high-energy tail, in a calculation of the Collins and Johnson type will produce a correspondingly richer J-plane structure in the isospin-zero amplitude. This possibility is presently being investigated.

1. P. D. B. Collins and R. C. Johnson, Phys. Rev. 182, 1755 (1969).
2. That the Collins-Johnson calculation is not flawless has been pointed out in D. H. Lyth, On the Collins-Johnson Bootstrap Calculation of the J = 1 $\pi\pi$ Scattering Amplitude, CERN TH-1143, March 1970, unpublished report. A recent repetition of the Collins-Johnson calculation with a slightly different technique tends to confirm some of the objections raised by Lyth.[5]
3. G. F. Chew and D. R. Snider, Phys. Rev. D 1, 3453 (1970).
4. G. F. Chew and D. R. Snider, UCRL-20033, July 1970.
5. Bryan Webber, private communication (Lawrence Radiation Laboratory), 1970.

THE AFS EQUATION AND COMPLEX REGGE POLES

Michael N. Misheloff

Regge trajectories occurring in complex conjugate pairs contribute oscillatory components to total cross sections and therefore may explain recent total cross-section measurements. The oscillations are periodic in ln s. The plausibility of complex poles comes from multiperipheral models in which an additional link in the chain is permitted when ln s increases by a definite quantity.

The J-plane structure of the solution of the AFS equation was studied. Positions and residues of poles were numerically determined. The leading poles with vacuum quantum numbers were found to be the following:

1) A real pole at J = 0.255
2) A complex conjugate pair of poles at J = - 0.73 ± 1.41 i
3) A complex conjugate pair at J = - 1.35 ± 3.36 i.

The second maximum in the total cross section arising from the first pair of complex conjugate poles occurs at S = 43 $(\mathrm{GeV})^2$. The contribution of the complex conjugate pair is 1-1/2% of that of real pole at this point. When the kernel was multiplied by a factor of five, the leading pole moved to J = 0.91 and the first complex conjugate pair moved to J = - 0.63 ± 1.91 i. Under these conditions, the second maximum occurs at S = 8 $(\mathrm{GeV})^2$; the contribution of the complex conjugate pair is 3-1/3% of that of the real pole at this point.

PRODUCTION CROSS SECTIONS IN THE MULTIPERIPHERAL MODEL

James A. Ball*† and G. Marchesini*‡

The total cross section for the multiperipheral model is obtained by solving a Bethe-Salpeter equation. We show that the N-particle production cross sections are given directly in terms of the eigenvalues and eigenfunctions of this Bethe-Salpeter equation, and hence are directly related to the Regge pole parameters. In simple models of Regge poles based on the multiperipheral model, the production cross sections are completely determined. Results are given for several simple cases including the Chew and Snider model of the Pomeranchuk.

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NATURAL PARITY QUANTUM NUMBER AND THE PARTIAL-WAVE ANALYSIS OF MULTIPERIPHERAL EQUATIONS

Marcello Ciafaloni and Harry Yesian*

The crossed partial-wave analysis of the multiperipheral equations has been extended to the natural parity quantum number. At nonvanishing momentum transfer, reflection symmetry simplifies the equations, diagonalizing a discrete index κ, which assumes the meaning of a parity index, as first conjectured by Carleton DeTar.[1] At vanishing momentum transfer a selection rule has been obtained, according to which an output Regge pole of Toller quantum number M = 0 and natural parity σ can be coupled only to input Regge poles having product of natural parities equal to σ. Consistency of this result with the t = 0 limit has been shown, and some possible implications of the election rule have been discussed.

*University of California-San Diego, La Jolla, California 92037.
1. Carleton DeTar, private communication (Lawrence Radiation Laboratory).

MULTIPERIPHERAL MODEL PREDICTIONS FOR INCLUSIVE EXPERIMENTS

James S. Ball,*† G. Marchesini,*‡ and Kent Jolley*†

The predictions of single-particle distributions from the multiperipheral model are being studied. The incident and target particles considered are pions and protons. This work is an attempt to compare quantitatively the multiperipheral model predictions with experimental data.

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DIFFRACTIVE MODEL WITH s-CHANNEL UNITARITY

James S. Ball*† and F. Zachariasen‡

This work is a continuation of a factorized model of multiparticle production which is consistent with s-channel unitarity and still gives an elastic scattering amplitude of the form isf(t). The model yields a nonlinear integral equation for f which is solved by computer. The results are in strikingly good agreement with p-p elastic scattering data. These results are generalized to consider diffractive quark-quark scattering in an attempt to produce a model of diffraction which incorporated the results of the additive quark model.

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GENERALIZATION OF THE AFS MULTIPERIPHERAL MODEL TO THE $J^P = 0^-$ MESON OCTET

Daniel R. Avalos*

Work is being done to include in the original AFS multiperipheral model[1] the complete $J^P = 0^-$ meson octet exchange instead of pion-pole dominance alone. The aim of this investigation is to see whether the predictions of the model, in the exact and broken SU(3) symmetry limits, are in better quantitative agreement with the experimental situation than the original one.

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*Fellow of the National Research Council of Argentina.

1. D. Amati, S. Fubini, and A. Stanghellini, Nuovo Cimento 26, 896 (1962).

PARTICLE PRODUCTION AND STRONG INTERACTION DYNAMICS

Clifford Risk*

With the advent of the Serpukhov, NAL, and CERN (colliding beam) accelerators, a large part of the attention to particle physics will be focused on particle production processes as a tool for understanding strong interaction dynamics. We are engaged in a comprehensive investigation of particle production models, a phenomenological comparison of them with present accelerator data, a prediction of measurements at the new accelerators, and an application of these results to the design of new experiments at NAL. This work is progressing in several stages, some of which are completed.

A. Comparison to Cosmic Ray Data

Using two models--one based on the Feynman prediction that secondaries produced have the distribution d^3p/E, and one based on the multiperipheral model--we obtained[1] a sensible fit to the Michigan cosmic ray data of pp collisions at 200 GeV. Among other things, we examined momentum distributions, angular distributions, multiplicity dependence, and Yang's limiting fragmentation hypothesis. In a subsequent work,[2] further theoretical considerations were made. This work is completed.

B. Theoretical Considerations of Particle Production Processes[3]

While the multiperipheral model provides a precise prescription for particle production processes (with no free parameters in the ABFST version), it is equally important to understand to what extent one is forced to the ideas of the multiperipheral model. In this work, we start with a detailed study of the constraints on particle production imposed by phase space alone. (This gives essentially Fermi's model.) Next, we add the constraint of the experimentally observed $\exp(-Ap_T^2)$ law. (This gives us Van Hove's model. Van Hove has been kind to send us the computer program generating his model.) Next, we add the experimentally observed fact that the incident particle has elasticity 0.5. We then find that we end up with essentially the multiperipheral model--namely, momentum transfers between neighboring ordered π momenta are small. This work is a theoretical prelude for the work to follow. We anticipate completion about November 1.

C. Experimental Comparison with a Simplified Multiperipheral Model (MPM)

Refining the simplified version of the MPM used in Ref. 1, we use four diagrams ($pp \to pA$, $\pi \pm pA$, $A\pi A$--where A denotes a

missing mass) and fit the momenta distributions of secondaries in pp collisions at 6, 12.4, 192., 200-800 GeV. We anticipate completion about October 15.

D. Experimental Comparison with the Chew-Pignotti Model

With the theoretical knowledge from B and the phenomenological results of C, we now compare the full MPM of Chew-Pignotti.[4] We handle phase space exactly with the Berkeley SAGE program, and compare the data at all multiplicities, for all energies, and all secondaries with the model. We have found that the careful handling of phase space--hitherto incapable of solution by theorists until the advent of SAGE--has important modifications on results of Ref. 1. We anticipate completion December 1.

E. Further Extensions

Among further extensions of our work, we consider the precise ABFST model, its comparison to data, and the evaluation of the diffraction peak through unitarity. There is further possibility of the development of our work to assist in the neutrino experiment at NAL and the search for quarks in cosmic rays.

*AEC Postdoctoral Fellow.

1. L. Caneschi, D. E. Lyon, Jr., and Clifford Risk, Phys. Rev. Letters 25, 774 (1970).
2. Donald E. Lyon, Jr., Clifford Risk, and Don Tow, Angular Distributions from Multiparticle Production Models (UCRL-19884; to be published in Phys. Rev., Dec. 1970).
3. The work reported in Sec. B-E is being done in collaboration with D. E. Lyon, Jr. (University of Michigan), J. Friedman, J. Lynch, and L. Stevenson (LRL).
4. G. F. Chew and A. Pignotti, Phys. Rev. 176, 2112 (1969).

ANGULAR DISTRIBUTIONS FROM MULTIPARTICLE PRODUCTION MODELS

Donald E. Lyon, Jr.,* Clifford Risk,† and Don M. Tow

Using $\exp(-Ap_T^2)(d^3p/E)$ as the momentum distribution of secondaries produced in ultra-high-energy collisions--a result predicted by the multiperipheral model,[1] by Feynman's parton model,[2] and by Cheng and Wu's consideration of hadrons as extended objects with many internal degrees of freedom[3]--we obtain the characteristic features of the angular distribution. We discuss the dependence on incident energy, mass of secondaries, and the value of A. We find that the c. m. angular distribution in the variable $\eta_{c.m.} = -\ln \tan(\theta_{c.m.}/2)$ has a two-bump structure, whereas the lab angular distribution in $\eta = -\ln \tan\theta_1$ is flat. This difference leads us to a discussion of the transformation between c. m. and lab angular distributions. We find that the usual relativistic approximation of the exact transformation leads to incorrect results. Finally, we show that these momentum and angular distributions approach limiting distributions.[4] This work has been completed.[5]

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1. L. Bertocchi, S. Fubini, and M. Tonin, Nuovo Cimento 25, 626 (1962); D. Amati, A. Stanghellini, and S. Fubini, Nuovo Cimento 26, 896 (1962).
2. R. P. Feynman, The Behavior of Hadron Collisions at Extreme Energies, in High Energy Collisions--Third International Conference (Gordon and Breach, 1969).
3. H. Cheng and T. T. Wu, Phys. Rev. Letters 23, 1311 (1969).
4. J. Benecke, T. T. Chou, C. N. Yang, and E. Yen, Phys. Rev. 188, 2159 (1969).
5. Donald E. Lyon, Jr., Clifford Risk, and Don M. Tow, Angular Distributions from Multiparticle Production Models (UCRL-19884; to be published in Phys. Rev., Dec. 1970).

POLE-CUT PARAMETRIZATION OF CHARGED PION PHOTOPRODUCTION IN TERMS OF COMPLEX CONJUGATE PAIRS OF REGGE POLES

J. S. Ball,*† H. J. W. Müller,** and B. K. Pal

We attempt to fit the forward charged pion photoproduction data by parametrizing Regge pole-cut combinations in the region $t < 0$ in terms of complex conjugate pairs of Regge poles. The pion-Pomeranchuk cut is taken into account by this method. The exchange of the A_2 meson is also considered. Predictions of the differential cross section and the asymmetry parameters for pion production by linearly polarized photons and polarized target nucleons are found. The results are in good agreement with pion photoproduction data for laboratory photon energies ranging from 3.4 to 18 GeV and t values up to $-0.2\ (\mathrm{GeV}/c)^2$. The results are contained in UCRL-20057.

A STUDY OF COMPLEX REGGE POLES IN ABFST MULTIPERIPHERAL MODEL

Sun-Sheng Shei

The multiperipheral model of ABFST[1] is used to study complex Regge poles. We use the trace approximation to solve the integral equation. The equations determining complex Regge poles for both $t = 0$ and $t \neq 0$ cases are derived. For the case of $t = 0$, we find the position of complex Regge poles and discuss their dependence on the pion mass. The behavior of these poles as t approaches the threshold has also been studied. It is found that there are an infinite number of complex Regge poles that have a point of accumulation at $\mathrm{Re}\ \alpha = -1/2$ when t approaches the threshold.

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1. D. Amati, S. Fubini, and A. Stanghellini, Nuovo Cimento 26, 896 (1962); L. Bertocci, S. Fubini, and M. Tonin, Nuovo Cimento 25, 626 (1962).

MULTIFACTORIZATION AND THE FOUR-REGGEON VERTEX FUNCTION IN THE DUAL RESONANCE MODELS. I

Loh-ping Yu

By repeatedly factorizing the Koba-Nielsen representation of the N-point dual amplitude, we can obtain an amplitude with an arbitrary number of excited legs.[1] In particular, we find an operator form of the four-Reggeon vertex function.

1. L. P. Yu (UCRL-19714, February 1970), Phys. Rev. (to be published).

GENERAL TREATMENT ON THE MULTIPLE FACTORIZATION IN THE DUAL RESONANCE MODELS—AND THE N-REGGEON AMPLITUDES. II

Loh-ping Yu

We present a compact way of carrying out repeated factorizations on the dual amplitude. Prescriptions are given for writing down the multiply factorized tree amplitudes. As an application of the prescriptions, we derive the N-Reggeon amplitude.[1]

1. L. P. Yu (UCRL-19810, April 1970), Phys. Rev. (to be published).

COMPUTER PROGRAM FOR THE FIVE-POINT FUNCTION

Bryan R. Webber

A computer program, which calculates the five-point generalization of the Veneziano function with high efficiency for all values of the arguments, was completed and is now in regular use for the fitting of experimental data.

S-CHANNEL HELICITY CONSERVATION IN PROCESSES INVOLVING POMERANCHUK EXCHANGE

Uri Maor* and J. E. Lang†

Evidence has accumulated over the past year indicating that Pomeranchuk exchange conserves S-channel helicity.[1] We are attempting to extract information about the Pomeranchuk's T-channel couplings from this evidence. In particular, it has been noted[2] in some simple cases that the couplings of the Pomeranchuk tend to enforce threshold and pseudothreshold constraints over "large" values of momentum transfer.

Work is in progress to extend this idea to reactions with more complicated kinematics.

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1. F. J. Gilman, J. Pumplin, A. Schwimmer, and L. Stodolsky, Phys. Letters 31B, 387 (1970).
2. Uri Maor, Mass Dependent Phenomena and S-Channel Helicity Conservation in Photoproduction of Rho Mesons, University of California–Berkeley Preprint, 1970.

SYMMETRICAL DUALITY VERTEX

Henry P. Stapp

The Veneziano model combines the contributions of an infinite number of particles in such a way as to get a simple final expression that satisfies a large number of previously formulated theoretical conditions, and fits a wide range of experimental data. However, attempts to make it satisfy unitarity have encountered great difficulties. As a step toward unitarization, a symmetrical form of the basic three-particle vertex has been constructed.[1] This vertex is, from the conventional point of view, the fundamental building block of the theory. However, it is not exhibited in an explicit way by the model, which gives directly the combined contributions of all particles. Straightforward attempts to extract the vertex yield a form that is unsymmetrical in the three equivalent legs of the vertex, and that must be used by combining it with unsymmetrical forms of the other vertices. A completely symmetrical form has been constructed but has not yet been exploited.

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1. Henry P. Stapp, Nuovo Cimento 66, 497 (1970).

REGGE THEORY FROM FEYNMAN AMPLITUDES

Clifford Risk*

Much of our intuition on the Regge analyticity of scattering amplitudes is developed from our physical ideas of the properties of particles and their interactions. These intuitive results can then be checked with field theoretic frameworks. We have completed the study of two of these intuitive results in field theory models.

A. Compositeness, Feynman Diagrams, and the Reggeized Absorption Model

The Reggeized absorption model has been used to study a large number of quasi-two-body reactions.[1] The model has been intuitively proposed from ideas of multiple scattering. We have derived the model from a Feynman diagram that features double Reggeon exchange in the cross channel and propagation of composite particles (described by Reggeons with signature) in the direct channel. Our derivation involves the compositeness ideas of Feynman and Yang, uses the theoretical techniques of Gribov and Polkinghorne, and yields the absorption model of HPKR. This work has been completed.[2,3]

B. Regge Effects in Weak Amplitudes

Using the theoretical techniques of A, we studied the presence of Regge effects in weak amplitudes. We showed that the double spin flip scattering amplitude displays a fixed pole at $J = -1$ and a moving amplitude at $J = \phi(t) - 2$, and we obtained the asymptotic behavior of the electromagnetic form factor. This work has been completed.[4]

*AEC Postdoctoral Fellow.
1. F. Henyey, G. L. Kane, J. Pumplin, and M. Ross, Phys. Rev. 182, 1579 (1969) (referred to as HPKR).
2. Clifford Risk, The Derivation of the Absorption Model from Feynman Diagrams, UCRL-19453, January 1970 (a preliminary version presented as lecture notes).
3. Clifford Risk, Compositeness, Feynman Diagrams, and the Reggeized Absorption Model (UCRL-19831, June 1970), Phys. Rev. (to be published).
4. Clifford Risk, Phys. Rev. 2D, 387 (1970).

ANALYTICITY OF FEYNMAN AMPLITUDES

Clifford Risk*

The study of analytic properties of Feynman diagrams has been consistently used as a means of investigating analyticity of amplitudes ever since the later 1950's. A particularly powerful technique has been the majorization method. A definitive treatise on this method was published in Russian[1] by Dr. I. T. Todorov. With the assistance of Dr. Todorov, who spent 1968-70 at the Institute for Advanced Study, Princeton, we have completed a translation of the Russian text, and it will be published by Pergamon Press.[2]

*AEC Postdoctoral Fellow.
1. I. T. Todorov, Analytic Properties of Feynman Graphs in Quantum Field Theory (Bulgarian Academy of Sciences, Sophia, 1966).
2. I. T. Todorov, Analytic Properties of Feynman Diagrams in Quantum Field Theory (to be published by Pergamon Press, 1970).

PROPERTIES OF LANDAU CURVES

Clifford Risk*

The properties of Landau curves of Feynman amplitudes can be characterized elegantly with the theory of algebraic curve theory.[1,2] Tullio Regge[3] has been engaged for the last few years in a comprehensive work to characterize all Landau curves, with the intent of describing the analytic properties of the S matrix. At the request of Regge, we extended some earlier results to a case of interest.[4] Because of other research commitments, we have not pursued this work intensively.

*AEC Postdoctoral Fellow.
1. Clifford Risk, J. Math. Phys. 9, 2168 (1968).
2. Shreeram Abhyankar and Clifford Risk, Algebraic Curve Theory and the Envelope Diagrams, in Analytic Methods in Mathematical Physics, Robert P. Gilbert and Roger G. Newton, Eds. (Gordon and Breach, New York, 1970), pp. 15-27.
3. Tullio Regge, The Fundamental Group of Poincare and the Analytic Properties of Feynman Relativistic Amplitudes, Nobel Symposium 8, Nils Svartholm, Ed. (John Wiley & Sons, New York).
4. Clifford Risk, private communication to Tullio Regge, 1970.

UP-DOWN ASYMMETRY IN INELASTIC ELECTRON-POLARIZED PROTON SCATTERING

Robert N. Cahn* and Y. S. Tsai†

We have investigated the up-down asymmetry in inelastic electron scattering from polarized protons. It is shown that the contributions from (possible) T violation and α^3 effects can be separated experimentally. We have demonstrated that the contribution of bremsstrahlung emission to the asymmetry is negligible. An expression for the two-photon exchange contribution is obtained, assuming a proton intermediate state and $N^*(1238)$ final state. The expression has been evaluated numerically and found to be

one order of magnitude smaller than the observed asymmetry. A general formalism for calculating the up-down asymmetry is presented and its physical significance discussed. The relation between T violation and the measurement of the asymmetry given by Christ and Lee[1] is sharpened and the experimental results of a Berkeley-SLAC collaboration discussed.

The work has been completed and the results published.[2]

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1. N. Christ and T. D. Lee, Phys. Rev. 143, 1310 (1966).
2. Robert N. Cahn and Y. S. Tsai, SLAC-PUB-722 and Phys. Rev. (to be published).

HIGH-ENERGY HADRON-DEUTERON SCATTERING*

C. J. Joachain† and C. Quigg‡

We review theoretical descriptions of hadron-deuteron scattering at high energies. All the specific models have in common the Glauber approximation as their principal ingredient. We devote considerable effort to a discussion of forward elastic scattering, for which the theories have reached the highest degree of refinement. We detail the modifications to the simple theory which have emerged from fine structure in experimental cross sections. The relation between the Glauber picture and Regge theory in analyzed, and the present incompleteness of both approaches is exposed. Brief remarks are made on the anomalous thresholds in energy variables that occur for loosely bound systems such as the deuteron. Finally, we discuss more basic generalizations of the Glauber method to include inelastic scattering of the projectile or of one of the constituent nucleons within the deuteron. A few specific experimental tests are listed. By formulating diffractive excitation of the projectile in terms of the multiple scattering series, we show how unstable hadron-nucleon elastic scattering may be explored.

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CENTRIFUGAL BARRIER EFFECTS IN MESONIC DECAYS

C. Quigg* and Frank von Hippel†‡

We have suggested that an approximation to the usual multichannel Breit-Wigner resonance formula with centrifugal barriers will permit a more sophisticated and more organized analysis of mesons which decay into many channels.[1] This amplitude describes the kinematics of the decay processes, and the kinematical influence of one decay mode upon another.

We also propose to use the multichannel resonant amplitude as a theoretical tool, to discover what the properties of meson resonances would be if dynamics were negligible. A specific suggestion is that the mesons of spin 3, 4, 5 on the leading trajectory should fission unless dynamical effects are important.

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1. C. Quigg and F. von Hippel, UCRL-19826.

EXPERIMENTAL STATUS OF CURRENT ALGEBRA

Frank von Hippel*† and Robert N. Cahn‡

We are examining the reliability of various tests of current algebra. The various

models employed for calculating the Adler-Weisberger sum rule, the Adler consistency condition, and soft-meson theorems are being examined in light of the most recent experimental data. Other tests, such as the Cullen-Treiman relations, may be investigated also. Special consideration will be given to tests of the $SU_3 \otimes SU_3$ symmetry-breaking scheme of Gell-Mann, Oakes, and Renner.[1]

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‡NSF Predoctoral Fellow.
1. Murray Gell-Mann, R. J. Oakes, and B. Renner, Phys. Rev. 175, 2195 (1968).

A π-B EXCHANGE-DEGENERATE MODEL FOR V^0-Δ^{++} PRODUCTION

G. S. Abrams (Trilling-Goldhaber Group) and U. Maor*†

The forward differential cross section of ρ-Δ production is shown to be reproduced quantitatively by an evasive Reggeized one-pion exchange model which smoothly reduces to the Born term at the pion pole. Assuming exact π-B exchange degeneracy leads to predictions for ω-Δ production that are in agreement with the experimental s and t dependences. Similar agreement is found for K^*-Δ production.

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†Supported by the Air Force Office of Scientific Research, Office of Aerospace Research, United States Air Force, under Grant No. AF-AFOSR-68-1471.

A MODEL OF THE INTERACTION BETWEEN TWO OVERLAPPING RESONANCES

Chun-Fai Chan

We present a simple model to illuminate the dynamical interplay between two nearby resonances. The model assumes that each resonance is associated with a different channel in the limit when interchannel coupling is absent. We study the changes induced in the real and imaginary parts of the resonance-pole positions when coupling is "turned on," and find that under some conditions the poles "attract" rather than "repel."

The relevance of this model to the A_2 mesons is discussed.

B_5 FIT TO $K^+p \to K^0\pi^+p$ AT 11.7 GeV/c

Victor Waluch (Group A) and Dennis Sivers*

A phenomenological model based on the Bardakci-Ruegg amplitude, B_5, is being used to fit data on $K^+p \to K^0\pi^+p$.

*NSF Predoctoral Fellow.

FINAL STATE INTERACTIONS IN $K \to 3\pi$

Robert Mathews

Work is continuing on a project to understand the observed gentle slope of the Dalitz plot of $K \to 3\pi$ by assuming that it is caused only by "dressing" the bare weak interaction with strong final-state interactions. The method of calculation is based on the Khuri-Treiman dispersion relation. It leads to a singular integral equation whose kernel is proportional to the ππ scattering amplitude. A method for numerically solving singular integral equations on a computer has been devised and is being used. Various assumptions for I = 0 and I = 2 ππ scattering phase shifts have been made. The corresponding Dalitz plot slopes have been calculated. We are now attempting to include the I = 1, ππ, P-wave scattering in the calculation to see if this leads to a steeper slope. At a later stage of this calculation an attempt will be made to take into account the fact that at low energies the $\pi^+\pi^-$ channel has a lower channel into which it can decay, that is $2\pi^0$'s. This may produce an "electromagnetic correction" to the Dalitz spectrum.

$\pi\rho \to \pi\rho$ S-WAVE AMPLITUDE FROM OPE POTENTIAL

Chih Kwan Chen

The isospin 1, S-wave amplitude of the process $\pi\rho \to \pi\rho$ is considered with a u-channel pion exchange pole term as the input potential. The spin and isospin of the π and ρ are taken into account. The mass of the ρ is taken to be complex and an N/D integral equation with a complex normal threshold is considered. The purpose of this research is to investigate the A_1 meson. Our present result suggests that there is no nearby A_1 -meson pole nor is there any nearby virtual bound state from this simple one-pion exchange potential.

A SLIGHTLY DAMPED REGGE POLE AS A BACKGROUND CONTRIBUTION

E. O. Thorland*

The contribution to a scattering amplitude of a single Regge pole may be made square-integrable in the energy variable by assuming that a small exponential damping factor of the form $\exp[-s\epsilon(t)]$ multiplies the Regge amplitude. Thus it may be lumped into the background integral. This trick allows one to perform a cross-channel partial-wave expansion solely in terms of unitary SU(1, 1) irreducible representations. The partial-wave amplitude for such a Regge pole can be shown to be closely related to a MacRobert's E function. The contribution to the amplitude divides quite naturally into an infinite sequence of undamped Regge poles and a background term. As $\epsilon \to 0$, the infinite sequence of undamped poles becomes finite and contains only poles with angular momentum less than the angular momentum of the damped pole. An investigation of possible connections between damped poles and the exponential decay observed in elastic p-p scattering is being carried out.[1]

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1. C. W. Akerlof et al., Phys. Rev. Letters 17, 1105 (1966).

DUAL RESONANCE MODELS FOR VECTOR CURRENTS

J. H. Weis

Multiple factorization of the dual resonance model (DRM) has been studied and we have shown how to manifestly exhibit complete factorization without the presence of spurious states.[1]

Using these results, we have extended the model for conserved vector currents in the DRM to include the infinite set of universally coupled vector mesons.[2] One- and two-current amplitudes satisfying current algebra and factorizing on the M highest trajectories are constructed for a form factor falling like $(q^2)^{-M}$. Physically acceptable completely factorized amplitudes are not obtained in the limit $M \to \infty$, however. Complete factorization and unsubtracted dispersion relations in q^2 for single-current amplitudes are shown to indeed imply exponentially falling form factors. However, we then prove that no acceptable completely factorized two-current amplitudes can be constructed from a current coupling only to the universal vector mesons.

We have also studied in detail a class of phenomenological functions that can incorporate exponentially falling form factors while having good large-q^2 behavior (electroproduction scaling behavior, appropriate asymptotic spin dependence of form factors, etc.).[3] We believe these functions are very interesting, although we have not yet been able to satisfy the requirements of current conservation and factorization.

1. R. C. Brower and J. H. Weis, Nuovo Cimento Letters 3, 285 (1970).

2. R. C. Brower and J. H. Weis, Vector Currents and Current Algebra. III. Dual Resonance Model with Universally Coupled Vector Mesons, UCRL-19750, April 1970.
3. J. H. Weis, Dual Resonance Models for Vector Currents (Ph. D. thesis), UCRL-19780, May 1970.

CURRENT ALGEBRA

Perry Shers

The previously described work on extrapolating the results of current algebra and PCAC for pion-nucleon two-body scattering to the physical region by means of S-matrix methods has been essentially completed; a detailed discussion of the method and of the results is being prepared.

ASYMPTOTIC SUM RULES

Perry Shers

The analytic structure and general form for high energies ("Regge" poles or cuts) of the scattering amplitude for two bodies at fixed t have been combined to obtain a new class of exact sum rules for the parameters of such asymptotic descriptions. The presence of a free variable in the rules permits the simultaneous determination of all the parameters. When combined with those obtained by differentiation, the rules can be put into forms in which the scattering for low energies dominates and which are, therefore, useful for estimating these parameters. Finally, either these rules or similar ones utilizing dispersive and fixed variables which facilitate saturation with experimental data may be used to estimate the parameters for large negative values of t. A detailed numerical study is under way.

RELATIVISTIC WAVE EQUATION

Joseph V. Lepore and Robert J. Riddell, Jr.

In our last report we discussed the nature of the solutions of a wave equation of the Bakamjian-Thomas[1] type for the case of an interaction due to the time component of a massive vector field. The solutions of this integral equation were shown to behave as p^{-s} at large momentum, with s between 1 and 2.

Because of this power behavior it seemed appropriate to extend our previous analysis by making a Mellin transformation of the momentum-space wave function. The analytic properties of the kernel of the new integral equation then determine the behavior of the wave function at both large and small momenta. The new kernel has a Cauchy type singularity. The choice of a contour of integration for the inverse Mellin transformation is made by demanding that the wave function be integrable for large momenta and that the transformed kernel be hermitian. The integral equation may therefore be reduced to a Fredholm equation by a method due to Vekua.[2] This holds for both bound and scattering states. We are thus able to prove that the solutions for the bound and scattering states are unique.

The energy value and wave function for the lowest S-wave bound state has been calculated for various values of the mass of the vector particle and the coupling. The calculation has been done in such a way that the mass of the vector particle may be as small as desired. We may thus compare our results with the usual Coulomb energy. The agreement in the appropriate limit is excellent.

The computer program for the scattering wave function has been prepared and is now being debugged. A report on this work is in the final stages of preparation.

1. B. Bakamjian and L. H. Thomas, Phys. Rev. 92, 1300 (1953).
2. W. Pagorzelski, Integral Equations (Pergamon Press, New York, 1966), p. 511.

TWO-BODY GREEN'S FUNCTION

Joseph V. Lepore and Robert J. Riddell, Jr.

We have begun a study of the two-body Green's function for spin-zero particles interacting through a massive vector meson. Only the lowest order approximation to the interaction operator is retained. We find that we are led to a non-Fredholm integral equation. A study of this equation by using the Mellin transformation is planned.

DIRAC EQUATION

Joseph V. Lepore and Robert J. Riddell, Jr.

The conventional treatment of the solutions of the Dirac equation for an electron in a Coulomb field is based on a power series expansion of the radial wave function. We have studied this problem by making a Mellin transformation of the momentum-space wave function. The kernel of the integral equation is not of the Fredholm type. The Mellin transformation leads to a singular integral equation and then directly to the usual solution. It clearly exhibits the origin of the behaviors at the origin and at infinity.

S-MATRIX INTERPRETATION OF QUANTUM THEORY

Henry P. Stapp

The attempt to make the S matrix the fundamental quantity of quantum theory meets with the apparent difficulty that the S matrix refers to asymptotic measurements performed in the infinite past and infinite future, whereas actual measurements are performed at finite times. An examination of the logical structure of quantum theory shows, however, that all measurements depend on the validity of asymptotic approximations, and that the fundamental logical quantity of the quantum theory is indeed the S matrix.[1,2] A principal point, stressed already by Bohr, is that the wave function of the observed system has no physical meaning during the processes of preparation or measurement; the wave function of the observed system has meaning only insofar as the system can be considered isolated from the interactions associated with the processes of preparation and measurement. This is because the preparing and measuring devices, being in contact with the classical environment, cannot be represented by wave functions. The perennial problem of measurements in quantum theory is resolved by insisting that wave functions be regarded as images in the space of variables associated with the observed system of specifications on the preparation or measurement of the system, and that the correspondence between quantum wave functions and classical specifications be, fundamentally, a matter of empirical calibration. This leads to a natural understanding of the peculiar ontological status--neither subjective nor objective--of the thing that the wave functions of quantum theory represent.

1. Henry P. Stapp, How To Understand Quantum Theory, UCRL-19729, April 1970.
2. Henry P. Stapp, The S-Matrix Interpretation of Quantum Theory (UCRL-19863, June 1970), submitted to Phys. Rev.

ASYMPTOTIC OPERATORS IN LOCAL THEORIES OF OBSERVABLES

Ira Herbst

The structure of the $t \to \pm\infty$ limits of translated local operators is being investigated. The method employs a theorem of L. Landau[1] which shows these limits are local and that they may be smeared free fields. Such a result would have important implications for the Spin-Statistics Theorem in a local algebra theory.

1. Lawrence J. Landau, Asymptotic Locality and the Structure of Local Internal Symmetries, Commun. Math. Phys. 17, 156 (1970).

ON COLEMAN'S THEOREM FOR SCALE INVARIANCE

H. Genz*†

It is shown that Coleman's theorem for internal transformations is also valid for scaling transformations. This work has been completed.[1]

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†Present address: Institut fur Theoretische Kernphysik d. Universitat Karlsruhe, Karlsruhe, Germany.
1. H. Genz, Phys. Letters 31B, 146 (1970).

DERIVATION OF EQUAL-TIME COMMUTATORS INVOLVING THE SYMMETRIC ENERGY-MOMENTUM TENSOR AND APPLICATION*

H. Genz†‡

We consider $T_{\mu\nu}$, the conserved and symmetric tensor density of Poincare transformations. We have derived relations between the equal-time commutators $[i\, T_{0m}(x), X(y)]$ and $[i\, T_{00}(x), Y(y)]$, where X is any one of the operators $\phi, \partial_0\phi, J_0, J_1$, or J_{01} and Y is any one of the operators X or $\Box\phi$, $\partial^\mu\bar{\psi}\gamma_\mu$, $\partial^\mu J_\mu$, or $\partial^0 J_{0m}$. We then show that SU(2) $\otimes$ SU(2) charge current commutators together with the assumption that $[A_0^\alpha(x), \bar{\psi}(y)]_{x_0=y_0}$ is proproportional to $\bar{\psi}(x)\tau^\alpha\gamma_5\delta(\underset{\sim}{x} - \underset{\sim}{y})$ imply that

$$[A_k^\alpha(x), \bar{\psi}(y)\gamma_0]_{x_0=y_0} = \frac{1}{2}\bar{\psi}(x)\gamma_5\gamma_k\,\tau^\alpha\delta(\underset{\sim}{x} - \underset{\sim}{y})$$

$$+ i(y - x)_k[A_0^\alpha(x), f_m^+(y)\,\gamma_0]_{x_0=y_0}$$

[f denotes $(i\gamma^\mu\partial_\mu - m)\psi$]. The incompatibility of field algebra commutators with the assumption

$$\int d^3x[A_k^\alpha(x), \bar{\psi}(y)\,\gamma_0]_{x_0=y_0} \text{ is proportional}$$

$$\text{to } \bar{\psi}(y)\,\gamma_5\,\gamma_k$$

is evident. If ψ is the nucleon field it is shown that a certain form of the nucleon current leads to the above relation unless the right-hand side vanishes. If this requirement is imposed one obtains $g_{A_1} = g_\rho$, where $g_{A_1}\, a_\mu^\alpha(x)\,\gamma_5\gamma_\mu\,\frac{\tau^\alpha}{2}\psi(x)\,[g_\rho\, v_\mu^\alpha(x)\,\gamma^\mu\frac{\tau^\alpha}{2}\psi(x)]$, denotes the contribution of $A_1(\rho)$ to f_m in terms of the renormalized field $a_\mu^\alpha(v_\mu^\alpha)$. From this we find the relations

$$g_\rho = \frac{m_\rho^2}{f_\rho} \quad \text{and} \quad g_{A_1} = \left(\frac{m_\rho}{m_{A_1}}\right)^2 \frac{m_{A_1}^2}{f_{A_1}}$$

for the weak coupling constant f_ρ and f_{A_1}. This work is described in a Lawrence Radiation Laboratory report.[1]

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*This work was performed in collaboration with Dr. J. Katz, Purdue University, Lafayette, Indiana.
†NATO Postdoctoral Fellow.
‡Present address: Institut fur Theoretische Kernphysik d. Universitat Karlsruhe, Karlsruhe, Germany.
1. H. Genz and J. Katz, Derivation of Equal-Time Commutators Involving the Symmetric Energy-Momentum Tensor and Applications, UCRL-19438, December 1969; Nucl. Phys. B13, 401 (1970).

POSSIBLE BINDING OF A MAGNETIC MONOPOLE TO A NUCLEUS WITH A MAGNETIC DIPOLE MOMENT

Dennis Sivers*

An investigation was made into the binding of Dirac monopoles and free nuclei and the effect this binding would have on the interpretation of experimental monopole searches. The report[1] has been accepted for publication in Physical Review.

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*NSF Predoctoral Fellow.
1. Dennis Sivers, Possible Binding of a Magnetic Monopole to a Particle with Electric Charge and a Magnetic Dipole Moment (UCRL-19794), Phys. Rev. (to be published).

II. ATOMIC, STATISTICAL, AND PLASMA PHYSICS

MULTIPLE-SCATTERING EXPANSIONS FOR NONRELATIVISTIC THREE-BODY COLLISION PROBLEMS*

J. C. Y. Chen† and C. J. Joachain‡

A simple derivation of the three-body multiple-scattering expansions from the Faddeev equations is given for nonrelativistic elastic, inelastic, rearrangement, and breakup processes. The Faddeev approach to the multiple scatterings is compared with the Watson multiple-scattering theory and it is shown to be equivalent to a symmetric version of the Watson equations, treating all three particles on the same footing. The significance of the Faddeev-Watson expansion is interpreted diagrammatically. The advantages of these expansions lie in the fact that there is no disconnected diagram, suggesting a better convergence behavior. The modifications required by the inclusion of an intrinsic three-body interaction are investigated.

*To be published in Phys. Rev.
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‡Leave of absence from Physique Théorique et Mathématique, Faculté des Sciences, Université Libre de Bruxelles, Brussels, Belgium.

ELECTRON IMPACT EXCITATION OF SODIUM-LIKE IONS

Mehdi Golshani

We use the Coulomb-Born approximation to calculate the total cross section for the electron impact excitation of ionized atoms that have one external electron.[1] When the incident energy is high and the atom is highly ionized, we can use the eikonal and classical approximations in conjunction with the Coulomb-Born approximation. Then the scattering amplitude reduces to a one-dimensional path integral which, in turn, can be reduced to any desired accuracy, to a sum over integrals that can be evaluated analytically. Using this procedure, we have calculated the total cross sections for the heavily ionized atoms Fe^{15+}, Co^{16+}, Ni^{17+}, and Cu^{18+}. The same technique is being applied to the problem of electron impact ionization of heavily ionized atoms.

1. M. Golshani, Electron Impact Excitation of Heavily Ionized Atoms, UCRL-19731, February 1970.

FINE STRUCTURE OF HELIUM

James Daley and Charles Schwartz

Work is continuing on higher order corrections to the fine structure in the helium atom.

INHIBITED M1 DECAY IN ATOMS

Charles Schwartz

The usual theory of single photon emission in atoms is being extended so that one can have the relativistic corrections (of order v^2/c^2) to the current operator. This is needed to calculate the inhibited M1 decay from the 1s2s ^3S state of two-electron atoms and ions. The result is to be compared with measurements[1] underway at the Hilac and is also of interest in some astrophysical problems.

RADIATIVE CORRECTIONS TO LEVELS IN A STRONG COULOMB FIELD

Peter Mohr and Eyvind H. Wichmann

An attempt is being made to calculate the radiative corrections to the energy levels of an electron in a strong Coulomb field. The computation involves numerical evaluation of multidimensional integrals. Applications of the results would include determination of the Lamb shift in hydrogen-like ions with nuclear charge up to 20, and determination of the Z

dependence of corrections to fine structure in atoms with atomic number in the range 70-90.

1. R. Marrus, private communication (Lawrence Radiation Laboratory).

ELECTROMAGNETIC WAVE SCATTERING WITHIN A PLASMA IN THE TRANSPORT APPROXIMATION

K. Watson

The radiation transport equation is used to study scattering of electromagnetic waves by a plasma. Specific calculations are given for radar backscatter and cross polarization (to appear in Physics of Fluids, 1970).

TRANSPORT OF ELECTROMAGNETIC RADIATION ALONG CURVED RAY PATHS

Chau-wa Lau and K. M. Watson

The radiation transport equation is generalized to describe wave propagation along curved ray paths. (This is to appear in J. Math. Phys., 1970).

He^+ - H SCATTERING IN THE NEAR-ADIABATIC LIMIT

C. Joachain and K. Watson

The eikonal approximation is used to calculate the 1S → 2P transition in hydrogen scattered by helium ions.

BACKSCATTERING OF ELECTROMAGNETIC WAVES FROM IONOSPHERE

Yu-Yun Kuo

A turbulent fluid model has been used to study the backscattering of radio waves from the ionosphere. When the turbulence is strong the scattering cross section is rather large, and the change in the polarization of the signal after scattering is significant. Electrostatic turbulence is also under consideration. Although the magnitude of the cross section is as yet uncertain, we believe this model should be relevant in the aurora region which depends on the strong electrojet current.

MICROSCOPIC THEORY OF A MULTICOMPONENT SYSTEM OF CHARGED AND NEUTRAL PARTICLES. I. GENERAL QUANTUM STATISTICAL FORMULATION*

Franz Mohling† and Charles Ray Smith‡

Recent contributions[1] to the Lee-Yang-Mohling theory[2] of single-component quantum fluids have enabled the development of a new theory of the quantum statistics for a multicomponent nonrelativistic system of charged and neutral particles in thermal equilibrium. Explicit rules for calculating the grand potential and particle and photon momentum distributions are provided. The formalism not only simplifies and corrects an earlier version,[3] but also it has made possible clear and systematic procedures for removing many divergences that occur in the many-body theory of fully ionized gases.

*Submitted to J. Math. Phys.

†Physics Department, University of Colorado, Boulder, Colorado.

‡Faculty Fellow, supported by Associated Western Universities, Inc., through contract with the U. S. Atomic Energy Commission.

1. F. Mohling, I. RamaRao, and D. W. J. Shea, Phys. Rev. A1, 177, 192 (1970).
2. T. D. Lee and C. N. Yang, Phys. Rev. 117, 22 (1960); F. Mohling, Phys. Rev. 122, 1043, 1062 (1961).
3. F. Mohling and W. T. Grandy, Jr., J. Math. Phys. 6, 348 (1965).

MICROSCOPIC THEORY OF A MULTICOMPONENT SYSTEM OF CHARGED AND NEUTRAL PARTICLES. II. INVESTIGATION OF PROPERTIES OF PHOTONS*

Anup Bhowmik† and Charles Ray Smith‡

On the basis of the generalized mastergraph formulation of quantum statistics, the properties of photons in a nonrelativistic, multicomponent, fully ionized gas in thermal

equilibrium have been investigated. The photon self-energy is calculated by summation, to all orders, of selected diagrams, and it is suggested that the solution is formally exact. Next, the photon momentum distribution is calculated, in the high-temperature low-density limit, to second order in the fine-structure constant. Several nonperturbative results are obtained that are significant even in lowest order. Mass-renormalization is accomplished by means of the counterterm technique of the generalized master-graph theory. The investigation is valid for particle densities $\rho << 10^{24}$ particles/cm^3 and for absolute temperatures $T \leq 10^6$ °K (but large enough for a high degree of ionization).

*Submitted to J. Math. Phys.
†Physics Department, University of Wyoming, Laramie, Wyoming.
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QUANTUM STATISTICAL THEORY OF A MULTICOMPONENT FULLY IONIZED GAS*

I. RamaRao† and Charles Ray Smith‡

A quantum statistical theory of a nonrelativistic fully ionized gas in thermal equilibrium has been developed on the basis of the linked-cluster expansion of the evolution operator. A systematic analysis of self-energy structures results in a master-graph formulation of quantum statistics. The formulation includes the technique of adding and subtracting in the Hamiltonian a single-particle operator. The present formulation corrects and improves an earlier version.[1] Explicit connections between the master-graph line factors and Green functions are provided, so that a long-overdue comparison of the Mohling master-graph theory[2] with other quantum statistical theories is clarified.

*To be published in Phys. Rev. A.
†Department of Physics, Stanford University, Stanford, California.
‡Faculty Fellow, supported by Associated Western Universities, Inc., through contract with the U. S. Atomic Energy Commission.

1. F. Mohling and W. T. Grandy, Jr., J. Math. Phys. 6, 348 (1965).
2. F. Mohling, Phys. Rev. 122, 1062 (1961).

LINEAR RESPONSE DESCRIPTIONS OF A NONRELATIVISTIC EQUILIBRIUM PLASMA

E. E. Ganfield* and Charles Ray Smith*

The problem of determining properties of a plasma by the scattering of external particles or photons is of experimental and theoretical interest. The present project is engaged in understanding the theoretical aspects of the above problem. Thus, the interrelationships of linear response functions, conductivity, dielectric function, and scattering cross sections have been established for a multicomponent fully ionized gas in thermal equilibrium. Also, the lowest order dynamic structure factor has been evaluated. Methods for performing higher order calculations of relevant correlation functions are still being developed.

*Supported by Associated Western Universities, Inc., through contract with the U. S. Atomic Energy Commission.

THEORY OF CLASSICAL, DOUBLE-TIME, STATISTICAL, GREEN'S FUNCTIONS: IDEAL GAS

Michael J. Smith*†

One of the central problems in the application of the theory of double-time, statistical, Green's functions (classical or quantum) has been the termination of the hierarchy of coupled equations-of-motion that are set up during the course of a calculation. An exact method of termination has been established for the chain of equations-of-motion associated with the ideal gas.[1] One then obtains the usual results found by other methods.

*Postdoctoral Fellow, Department of Physics, University of California–Berkeley.
†Present address: Naval Research Laboratories, Washington, D. C.
1. M. Smith, Phys. Rev. Letters 24, 1398 (1970).

THEORY OF CLASSICAL, DOUBLE-TIME, STATISTICAL, GREEN'S FUNCTIONS: COULOMB PLASMA

Michael J. Smith*†

Bogolyubov and Sadovnikov[1] have established a hierarchy of chassical Green's functions for a Coulomb plasma by varying the single-time distribution function of the Bogolyubov-Born-Green-Kirkwood-Yvon hierarchy with respect to an infinitesimal external field. The simplest decoupling of this system allowed them to obtain the usual Debye form for the correlation function.

In contradistinction to this approach, we establish a hierarchy by the equation-of-motion technique common to the development of hierarchies for quantum systems.[2,3] Termination of the hierarchy is achieved by simultaneously using both the random phase approximation[4] and the technique developed in a recent work.[5]

*Postdoctoral Fellow, Department of Physics, University of California, Berkeley.
†Present address: Naval Research Laboratories, Washington, D. C.
1. N. N. Bogolyubov, Jr., and B. I. Sadovnikov, Zh. Eksperin. i Teor. Fiz. 43, 677 (1962) [Soviet Phys. JETP 16, 482 (1963)].
2. N. N. Bogolyubov and S. V. Tyablikov, Dokl. Akad. Nauk SSR 126, 53 (1959) [Soviet Phys. Doklady 4, 589 (1959)].
3. D. M. Zubarev, Usp. Fiz. Nauk. 71, 71 (1960); Soviet Phys. Usp. 3, 320 (1960).
4. D. Pines and D. Bohm, Phys. Rev. 85, 338 (1952).
5. M. Smith, Phys. Rev. Letters 24, 1398 (1970).

III. ACCELERATOR THEORY

CROSSING OF AN INCOHERENT INTEGRAL RESONANCE IN THE ELECTRON RING ACCELERATOR*

Claudio Pellegrini† and Andrew M. Sessler

In one mode of operation of an electron ring accelerator (ERA), at the end of compression, rings are slowly moved through the radial integral betatron resonance $Q_r = 1$. Although the coherent radial oscillation frequency of the ring as a whole remains below unity, the oscillation frequencies of individual electrons are (incoherently) caused to pass through the resonance because of the additional focusing from ions trapped in the ring. In this paper the effect of field errors on ring major and minor radii is evaluated--theoretically--for the cases in which the spread in the square of the electron oscillation frequency (Δ^2) is (a) much larger and (b) much smaller than the contribution to the square of the oscillation frequency from the ions (Λ^2). It is shown that for the ERA, where case (b) applies, the increase in ring minor dimensions, for given field errors and rate of resonance crossing, is less than in case (a) by a factor of $(\Delta/\Lambda)^2$. Numerical examples show that the degradation of ring quality in case (b) should, with suitable attention to the design and construction of the ERA apparatus, be acceptably small.

*C. Pellegrini and A. Sessler, Crossing of an Incoherent Integral Resonance in the Electron Ring Accelerator (UCRL-19462, January 1970), Nucl. Instr. Methods (to be published).
†Permanent address: Laboratori Nazionali di Frascati, Frascati (Rome), Italy.

DIFFRACTION RADIATION BY A LINE CHARGE MOVING PAST A COMB: A MODEL OF RADIATION LOSSES IN AN ELECTRON RING ACCELERATOR*

R. D. Hazeltine,† M. N. Rosenbluth,† and A. M. Sessler

A calculation is given of the radiated

energy loss for a charged rod which moves at constant speed past an infinite set of parallel semiinfinite conducting plates of infinitesimal thickness, with the rod taken parallel to and at a fixed distance from the plate edges. The problem is analyzed by using the Wiener-Hopf technique, and the resulting formulas are evaluated analytically in the limits of high rod speed and low rod speed, and compared with numerical evaluation over the full range of speeds.

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*R. D. Hazeltine, M. N. Rosenbluth, and A. M. Sessler, Diffraction Radiation by a Line Charge Moving Past a Comb: A Model of Radiation Losses in an Electron Ring Accelerator (UCRL-19793, April 1970), to be published in J. Math. Phys.
†Institute for Advanced Study, Princeton, New Jersey.

STOCHASTICITY IN MANY-DIMENSIONAL NONLINEAR OSCILLATING SYSTEMS*

B. V. Chirikov,† E. Keil,‡ and A. M. Sessler

Qualitative analytic estimates of the stochasticity limit of one and many-dimensional nonlinear oscillating systems are derived by using the overlapping of first-order resonances as a criterion for stochasticity. Computational results obtained with several very simple transformations are compared with the analytic estimates.

Numerical studies significantly below the stochasticity limit of a many-dimensional nonlinear system revealed an example of a very slow instability--the first to the best of our knowledge.

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*B. V. Chirikov, E. Keil, and A. M. Sessler, Stochasticity in Many-Dimensional Nonlinear Oscillation Systems, CERN Internal Report ISR-TH/69-59, October 1969.
†Institute for Nuclear Physics, Novosibirsk, USSR.
‡CERN, Geneva, Switzerland.

PHYSICS WITH AND PHYSICS OF COLLIDING ELECTRON BEAMS*

Claudio Pellegrini† and Andrew M. Sessler

A review is given of colliding electron beam devices, their principles of operation, and the physics which has and can be done with them.

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*C. Pellegrini and A. M. Sessler, Physics With and Physics of Colliding Electron Beams, UCRL-19401, November 1969; and Comments on Nuclear and Particle Physics 4, 55 (1970).
†Permanent address: Laboratori Nazionali de Frascati, Frascati (Rome), Italy.

LOWER BOUNDS ON SELF-FOCUSING SO AS TO MAINTAIN RING INTEGRITY NEAR THE INITIATION OF ACCELERATION IN AN ELECTRON RING ACCELERATOR*

Claudio Pellegrini† and Andrew M. Sessler

We have found the relationships that must hold between the self-focusing forces of an electron ring and the magnetic field gradient defocusing forces if ring stability is to be achieved. The regime being studied is that near and just subsequent to the start of ring acceleration.

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*C. Pellegrini and Andrew M. Sessler, Lower Bounds on Self-Focusing So As to Maintain Ring Integrity Near the Initiation of Acceleration in an Electron Ring Accelerator (UCRL-19398 Rev., April 1970), Nucl. Instr. Methods (to be published).
†Permanent address: Laboratori Nazionali de Frascati, Frascati (Rome), Italy.

COMPUTATIONAL WORK IN SUPPORT OF THE COMPRESSOR IV AND COMPRESSOR V PROGRAMS OF THE ELECTRON RING PROJECT

L. Jackson Laslett

The present Compressor IV experiments being conducted by the Electron Ring Group at Berkeley will involve modifications in the configuration or dimensions of electrical components that provide and shape the magnetic field. The influence of these modifications

on ring formation and survival will be investigated as a part of the program to obtain an improved understanding of the conditions to be met in an effective device. Similarly the design of the future Compressor V will require well-considered decisions to be made concerning the nature and dimensions of the coils and related components of that device. To guide and interpret the work with Compressor IV, and to assist in the design of Compressor V, it therefore appeared desirable to have a computational program for simulating ring compression and extraction that is more flexible than that which was satisfactorily used in conjunction with the Compressor-III work. The earlier teletype-controlled computer program accordingly has been modified, by Barbara Levine, to permit new coils or revised coil dimensions to be readily introduced into the program while operating in direct teletype connection with the computer. This more versatile program is now in use. It remains to simulate eddy-current perturbations in a more convenient and adequate way that will be consistent with the improved versatility of the program. To achieve this end in a computationally efficient way suggests that such eddy-current effects might best be treated mathematically as perturbations, by an iteration technique, and computational tests recently completed have been encouraging in indicating that this procedure will provide results of entirely acceptable accuracy.

SINGLE-PARTICLE RESONANCE EFFECTS IN AN ELECTRON RING ACCELERATOR

L. Jackson Laslett

Evidence for the occurrence of single-particle resonance effects was seen in some of the past LRL experiments with electron ring compression, and such resonances potentially could be troublesome in future devices if the character of the magnetic fields inadvertently were such as to lead to their excitation. For this reason the quantitative theoretical analysis of axial-amplitude growth at and near potentially critical values of the field index has been carefully reviewed and refined with this specific application in mind. This analytic effort has been accompanied by direct computational solution of the differential equations assumed in the analysis, in order to guide and to monitor the theoretical work. Final checks of the results have also been provided by computational studies conducted by W. A. Perkins and A. C. Paul, who have employed either directly measured magnetic fields or fields that are computed exactly for a specific coil configuration, and who then have integrated the exact differential equations of particle motion in such fields. The following Abstract, which has been submitted to the American Physical Society, pertains to a report on this work that will be presented to the Society at its forthcoming Washington meeting.

BETATRON RESONANCE GROWTH IN AN ELECTRON RING ACCELERATOR

W. A. Perkins and L. J. Laslett

In an electron ring accelerator, electrons are often injected into a magnetic field with index $n = -(R/B)(dB/dR)$ of about 0.5. For extraction and axial acceleration of the ring, n must approach zero and several betatron resonances are crossed. The following of particles on a computer through simulated fields (which approximate the measured experimental fields) has elucidated which resonances are important and which magnetic field perturbations cause large growth for a particular geometry. Analytical formulas for resonance growth also have been derived and checked against the computer calculations. These equations indicate the important driving

terms of the field and are convenient for estimating the expected growth on traversing a resonance. Resonances at $n = 0.5$, 0.36, 0.25, and 0.20 have been investigated.

NUMERICAL SIMULATION OF ELECTRON RINGS

A. A. Garren and L. Jackson Laslett

The preceding report made reference to a multiparticle simulation code that was developed at the Los Alamos Scientific Laboratory, under the direction of Dr. Richard Morse, for the study of plasma phenomena. This code has now been modified to permit study of the r, z motion of relativistic ions and electrons in an electron ring device, and initial tests indicate that it is performing as intended. The program has recently been successfully operated also at Berkeley, where additional tests will be performed and certain improvements (devised jointly with LASL, and with Dr. Richard Christian, a LASL consultant from Purdue University) may be introduced before specific application to problems directly relevant to the Electron Ring Accelerator.

LINEAR INDUCTION ACCELERATOR FOR ERA EXPERIMENTS

A. A. Garren

A 4-MeV electron accelerator to be used as an injector for the ERA compressor has been constructed in Berkeley. Beam dynamics studies including space charge forces were carried out to determine apertures and the required strength and spacing of the focusing solenoids.

NEGATIVE MASS INSTABILITY OF ELECTRON RINGS

A. A. Garren

A simulation computer program is being developed to study the longitudinal instabilities of electron rings by tracking a large number of orbits in the $r - \theta$ directions under the influence of fields generated by density fluctuations of the ring. This should be useful in verifying linear theories and for seeing the growth of instabilities in the nonlinear regime.

STORAGE RING

A. A. Garren

Theoretical assistance on lattice design, orbit analysis, and beam transport was given to the electron storage ring project. The orbit analysis was based on the known fields of the air core magnets.

STORAGE RING

Lloyd Smith

A decision was made in the spring to pursue the technology of storing high intensity beams by constructing a magnetic storage ring of about 30 meters circumference capable of accepting the 1000-ampere 5-MeV electron beam produced by the Astron accelerator. The ring, scheduled to be completed toward the end of 1971, would be used to investigate various known collective instabilities and look for new ones. A considerable amount of work has been done on orbit dynamics; an appropriate alternating gradient lattice has been developed, and various linear and nonlinear effects arising from the finite length and large aperture of the magnetic dipoles and quadrupoles have been investigated. It appears that these effects are small enough not to confuse the study of collective effects.

An analysis was made of a collective phenomenon, the existence of which was only recently recognized.[1] If the beam suffers a closed orbit distortion because of field errors, the amplitude is influenced by electric and magnetic images in the vacuum chamber wall.

At the first moment these forces almost cancel, but the wall currents eventually die out because of the finite resistance of the wall, leaving a large net electric force on the beam. Quantitative expressions were derived for this effect and used to determine the material and thickness of the chamber wall.

1. Stephen Bodner, V. K. Neil, and Lloyd Smith, Decay of Image Currents and Some Effects on Beam Stability, Particle Accelerators (to be published).

SUPERCONDUCTING SYNCHROTRON

A. A. Garren and Lloyd Smith

A conceptual study was made of an alternating gradient synchrotron in the 50-100 GeV range, to be built with superconducting magnets in a tunnel adjoining the Bevatron area and making extensive use of Bevatron machine and experimental equipment. Our role in this effort was to provide a reasonable set of parameters for the synchrotron. The only conditions imposed on beam dynamics by the use of superconducting magnets are that the vacuum chamber should be circular in cross section rather than the usual elliptical shape, and that the dipoles and quadrupoles should be separate structures. An effort was made to meet these constraints efficiently. The final result was a machine of 80 meters radius and 10-centimeter bore diameter, consisting of 128 dipoles and 56 quadrupoles, plus special quadrupoles at four long straight sections. Since the circumference factor was 1.75, such a machine would yield 70-GeV protons at 50 kG and 84 GeV at 60 kG.

ANALYSIS OF CAVITY MODES IN THE ERA

Allen Entis and Lloyd Smith

The ERA compressor was treated as a metallic pill-box cavity, and an analysis made of the fields produced by the electron ring in the transient situation of initial entrance and later when the negative mass instability might begin to develop. This work is still in progress.

PUBLICATIONS AND PAPERS

1. G. S. Abrams and U. Maor, A π-B Exchange Degenerate Model for $V^0 - \Delta^{++}$ Production (UCRL-19792) Phys. Rev. Letters 25, 621 (1970).

2. Donald M. Austin, William H. Greiman, and William Rarita, Regge-Pole Model for pp and $\bar{p}p$ Elastic Scattering at High Energy (UCRL-19754), Phys. Rev. D. (to be publighed).

3. James S. Ball and Giuseppe Marchesini, Production Cross Sections in the Multiperipheral Model (UCRL-19816, May 1970), submitted to Phys. Rev.

4. Anup Bhowmik and Charles Ray Smith, Microscopic Theory of Multicomponent System of Charged and Neutral Particles. II. Investigation of Properties of Photons (UCRL-19412, March 1970), submitted to J. Math. Phys.

5. R. C. Brower and J. H. Weis, Nuovo Cimento Letters 3, 285 (1970).

6. R. C. Brower and J. H. Weis, Vector Currents and Current Algebra. III. Dual Resonance Model with Universally Coupled Vector Mesons, UCRL-19750, April 1970.

7. L. Caneschi, D. E. Lyon, Jr., and Clifford Risk, Angular Distribution of Multiparticle Events at High Energies (UCRL-19814), Phys. Rev. Letters 25, 774 (1970).

8. Colston Chandler and Henry P. Stapp, Macroscopic Causality Conditions and Properties of Scattering Amplitudes (UCRL-17734) J. Math. Phys. 10, 826 (1969).

9. Joseph C. Y. Chen, Chen-Show Wang, and Kenneth M. Watson, Electronic Transitions in Slow Collisions of Atoms and Molecules. III. Eikonal Approximation for

Nonclassical Scatterings, Phys. Rev. A1, 1150 (1970).
10. Joseph C. Y. Chen and Kenneth M. Watson, Electronic Transitions in Slow Collisions of Atoms and Molecules. II. Calculations of Wave Functions in the Eikonal Approximation (UCRL-18827), Phys. Rev. 188, 236 (1969).
11. Geoffrey F. Chew and Dale R. Snider, Multiperipheral Model Suggestion of a Damped Oscillatory Component in High Energy Total Cross Sections (UCRL-19409), Phys. Letters 31B, 75 (1970).
12. Geoffrey F. Chew and Dale R. Snider, Multiperipheral Mechanism for a Schizophrenic Pomeron (UCRL-19455), Phys. Rev. D1, 3453 (1970).
13. G. F. Chew, T. W. Rogers, and D. R. Snider, Relation Between the Multi-Regge Model and the ABFST Pion Exchange Multiperipheral Model (UCRL-19457, January 1970), Phys. Rev. (in press).
14. Geoffrey F. Chew, Quark or Bootstrap: Triumph or Frustration for Hadron Physics? (UCRL-19821, May 1970), Physics Today (to be published).
15. B. V. Chirikov, E. Keil, and A. M. Sessler, Stochasticity in Many-Dimensional Nonlinear Oscillating Systems, CERN Internal Report ISR-TH/69-59, October 1969.
16. Marcello Ciafaloni and Carleton DeTar, The 0(2,1) Decomposition of the Equal-Mass Multiperipheral Equation at $t = 0$ (UCRL-19417, November 1969), Phys. Rev. (to be published).
17. Joseph Coster and Henry P. Stapp, Physical-Region Discontinuity Equations for Many-Particle Scattering Amplitude. I. (UCRL-17484), J. Math. Phys. 10, 371 (1969).
18. Joseph Coster and Henry P. Stapp, Physical Region Discontinuity Equations for Many-Particle Scattering Amplitudes. II. (UCRL-17902), J. Math. Phys. 11, 1441 (1970).
19. Carleton E. DeTar and Dale R. Snider, Two-Fireball Phenomenon and the Multiperipheral Model (UCRL-19818), Phys. Rev. Letters 25, 410 (1970).
20. R. D. Field, Jr., and J. D. Jackson, Finite Energy Sum Rules, Duality Diagrams, and Hyperon Polarization in the Reaction $K^-n \to \pi^-\Lambda$, UCRL-19749, April 1970 (paper submitted to Conference on Polarization, Argonne National Laboratory, April 15, 1970).
21. Geoffrey C. Fox and C. Quigg, Compilation of Elastic Scattering Data, UCRL-20001, January 1970.
22. C. Garwin, Spinors from Vectors, UCRL-19730, March 1970.
23. H. Genz and J. Katz, Derivation of Equal-Time Commutators Involving the Symmetric Energy-Momentum Tensor and Applications (UCRL-19438), Nucl. Phys. B13, 401 (1970).
24. H. Genz, On Coleman's Theorem for Scale Invariance (UCRL-19411), Phys. Letters 31B, 146 (1970).
25. Mehdi Golshani, Electron Impact Excitation of Sodium-Like Ions (UCRL-19731, March 1970), submitted to Phys. Rev.
26. Ralph F. Guertin, Kinematical-Singularity Free Invariant Amplitudes for Two Particle Scattering Processes. I. (UCRL-19460 Rev., June 1970), submitted to J. Math. Phys.
27. R. D. Hazeltine, M. N. Rosenbluth, and Andrew M. Sessler, Diffraction Radiation by a Line Charge Moving Past a Comb: A Model of Radiation Losses in an Electron Ring Accelerator (UCRL-19793, April 1970), J. Math. Phys. (to be published).
28. Daniel Iagolnitzer and Henry P. Stapp, Macroscopic Causality and Physical Region Analyticity in S-Matrix Theory, Comm. Math. Phys. 14, 15 (1969).
29. J. D. Jackson and C. Quigg, Remarks on Pion Photoproduction (UCRL-19410, March 1970), Nucl. Phys. B (to be published).

30. C. J. Joachain and C. Quigg, High-Energy Hadron-Deuteron Scattering (UCRL-19851, June 1970), submitted to Rev. Mod. Phys.
31. Chau-Wa Lau and Kenneth M. Watson, Radiation Transport Along Curved Ray Paths (UCRL-19466, January 1970), J. Math. Phys. (to be published).
32. Michael N. Misheloff, The Triple-Regge Vertex (Ph. D. thesis), UCRL-19795, May 1970.
33. Franz Mohling and Charles Ray Smith, Microscopic Theory of a Multicomponent System of Charged and Neutral Particles. I. General Quantum Statistical Formulation (UCRL-19406, November 1969), submitted to Phys. Rev.
34. B. K. Pal, Veneziano Model for $np \rightarrow pn$ and $p\bar{p} \rightarrow n\bar{n}$ Scattering and Parity Doublet (UCRL-19441, January 1970), submitted to Phys. Rev.
35. Jerry L. Peacher and Kenneth M. Watson, Doppler Shift in Frequency in the Transport of Electromagnetic Waves through an Underdense Plasma (UCRL-19212), J. Math. Phys. 11, 1496 (1970).
36. Claudio Pellegrini and Andrew M. Sessler, Crossing of an Incoherent Integral Resonance in the Electron Ring Accelerator (UCRL-19462, January 1970), Nucl. Instr. Methods (to be published).
37. C. Pellegrini and A. Sessler, Lower Bounds on Self-Focusing So As To Maintain Ring Integrity Near the Initiation of Acceleration in an Electron Ring Accelerator (UCRL-19398 Rev., April 1970), Nucl. Instr. Methods (to be published).
38. Claudio Pellegrini and Andrew M. Sessler, Physics with and Physics of Colliding Electron Beams (UCRL-19401), Comments on Nuclear and Particle Physics 4, 55 (1970).
39. C. Quigg and F. von Hippel, Centrifugal Barrier Effects in Meson Decays, UCRL-19826, May 1970.
40. I. RamaRao and Charles Ray Smith, Quantum Statistical Theory of a Multicomponent Fully Ionized Gas (UCRL-19423, December 1969), Phys. Rev. 2A, 843 (1970).
41. William Rarita, Regge-Pole Fit to Serpukhov $\pi^- p$ Total Cross Section Data (UCRL-19442), Phys. Rev. D1, 3185 (1970).
42. Clifford Risk, Regge Effects in Weak Amplitudes (UCRL-19710), Phys. Rev. 2D, 387 (1970).
43. Clifford Risk, The Derivation of the Absorption Model from Feynman Diagrams, UCRL-19453, January 1970 (a preliminary version presented as lecture notes).
44. Clifford Risk, Compositeness, Feynman Diagrams, and the Absorption Model (UCRL-19831, June 1970), Phys. Rev. (to be published).
45. Clifford Risk, Analytic Properties of Feynman Graphs in Quantum Field Theory, by I. T. Todorov, translation from Russian to to English, to be published by Pergamon Press.
46. Andrew M. Sessler, The Acceleration of Particles by Collective Fields. I. (UCRL-19223), Comments on Nuclear and Particle Physics 3, 93 (1969).
47. Dennis Sivers, Possible Binding of a Magnetic Monopole to a Particle with Electric Charge and a Magnetic Dipole Moment (UCRL-19794, May 1970), Phys. Rev. (to be published).
48. D. Sivers and J. Yellin, Review of Recent Developments in Narrow Resonance Models (UCRL-19418, December 1960), submitted to Rev. Mod. Phys.
49. Michael J. Smith, Classical Green's Functions for the Ideal Gas (UCRL-19746), Phys. Rev. Letters 24, 1398 (1970).
50. Henry P. Stapp, Symmetrical Duality Vertex, Nuovo Cimento 66A, 497 (1970).
51. Henry P. Stapp, How to Understand

Quantum Theory, UCRL-19729, April 1970.
52. Henry P. Stapp, S-Matrix Interpretation of Quantum Theory, UCRL-19863, June 1970.
53. Don M. Tow, Some Predictions of the ABFST Multiperipheral Model (UCRL-19449), Phys. Rev. D2, 154 (1970).
54. K. Watson, Electromagnetic Wave Scattering Within a Plasma in the Transport Approximation, Phys. Fluids (to be published).
55. J. H. Weis, Dual Resonance Models for Vector Currents (Ph. D. thesis), UCRL-19780, May 1970.
56. Loh-ping Yu, Multifactorization and the Four Reggeon Vertex Functions in the Dual Resonance Models (UCRL-19714, February 1970), Phys. Rev. (to be published).
57. Loh-ping Yu, General Treatment in Multiple Factorizations in Dual Resonance Models and N-Reggeon Amplitudes. II. (UCRL-19810, April 1970), Phys. Rev. (to be published).

EXPERIMENTAL PHYSICS, GROUP A

Frank T. Solmitz in charge

I. BUBBLE-CHAMBER EXPERIMENTS

A. ASSOCIATED PRODUCTION EXPERIMENT

Frank S. Crawford, Jr., Joseph C. Doyle,* and LeRoy R. Price†

Between mid-1960 and mid-1961, the 72-in. hydrogen bubble chamber was exposed to π^+ and π^- beams at six different incident momenta from 1.030 to 1.325 GeV/c. About 1 000 000 pictures were taken, of which 3/4 have been analyzed at Berkeley and the remainder at the Universities of Wisconsin, Purdue, Johns-Hopkins, and Duke. Numerous results from this experiment have been published. In late 1964, an additional 110 000 pictures of π^- incident at 5 different momenta from 0.910 to 1.030 GeV/c were taken for analysis at Berkeley.

Radiative Pion Production

We are continuing our study of the two-prong and four-prong events in πp interactions, using events in which the gamma ray has materialized in the hydrogen.

Six-Pronged Events

Our analysis of six-pronged events produced in $\pi^{\pm}p$ interactions around 1 GeV/c is proceeding.

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B. K63 EXPERIMENT

An exposure of the 72-in. hydrogen bubble chamber to a K^- beam having lab momenta of 1.7, 2.1, 2.47, 2.59, 2.64, and 2.73 GeV/c was made, totaling 30 events/μb. Exposures with deuterium were taken at 2.1 and 2.7 GeV/c. The film was taken between mid-1963 and early 1965. More than 300 000 events have been measured.

Production and Decay of Cascade Hyperons

Philip M. Dauber* and Richard Muller

This study has been concluded.

Resonance Production in K^-p Interactions

J. Duboc,† P. H. Eberhard, R. D. Estes, J. H. Friedman, M. Pripstein, and R. R. Ross

Continuing the study of K^-p at 2.1 and at 2.6 GeV/c, we have focused our attention on the problem of the $\Sigma(1660)$. Additional evidence has been found for the existence of twin resonances from the $\Lambda\pi$ decay mode and the 2.1 GeV/c data. Effort has been made to find evidence of interference effects between the two resonances; but, in all our study so far, none was found. These results were reported at the Duke Conference on Hyperon Resonances.[1]

K^- Interactions in Deuterium

Angela Barbaro-Galtieri, Maxine Matison, and Alan Rittenberg

The deuterium film of path length 5

events/μb, equally divided between 2.11 and 2.65 GeV/c, has been scanned. Measurements have been made on Franckensteins and the Spiral Reader of 50 000 events of the following topologies: three or four prongs with or without a secondary decay, and one to four prongs with a vee. All ambiguities have been looked at on the scanning table, and the data are now in the final analysis stage.

The evidence for a $K\pi$ system in a $T = 3/2$ state is probably negative, although a possible enhancement in the $K^+\pi^+\pi^0$ mass plot will be investigated further. The other mass combinations in three- and four-prong states are now being searched for production of other resonances.

Study of K^-p Four-Pronged Reactions

Jerome H. Friedman, Alan R. Kirschbaum, and Ronald R. Ross

Approximately 48 000 K^-p interactions producing four charged particles have been measured on the Spiral Reader. Analysis is in progress. Using the one-pion-exchange reaction $K^-p \rightarrow K^-\pi^-\Delta^{++}$, we have measured the cross section for the process $K^-\pi^- \rightarrow K^-\pi^-$ in four ranges of $K\pi$ mass, from threshold to 1.04 GeV. Results will appear in UCRL-19426 (Revised) and will be submitted for publication.[2]

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1. R. D. Estes, J. Duboc, P. H. Eberhard, J. H. Friedman, M. Pripstein, and R. R. Ross, Remarks on the Existence of Two Σ(1660) Resonances, in Proc. 1970 Duke Conference on Hyperon Resonances (p. 279); UCRL-19824, May 1970.
2. A. R. Kirschbaum, P. M. Dauber, J. H. Friedman, E. Colton, and P. E. Schlein, An Upper Limit for the $T = 3/2$ $K\pi$ Elastic Cross Section (UCRL-19426, December 1969), submitted to Phys. Rev. Letters.

C. K65 EXPERIMENT

During the period from August 1965 to October 1967, the 25-in. hydrogen bubble chamber was exposed to a K^- beam of about 400 MeV/c. Roughly 1 400 000 pictures have been taken, 60 000 of which were in deuterium. The average track density was about 6 K^- per picture. All of the film has been scanned once, yielding 577 000 events. About 30 percent of the film has been scanned twice, and about 6 percent of the film has been scanned three times. A total of 435 000 measurements has been made. All events have been processed on the CDC-6600 computer, and the analysis is in progress.

Additional K^-p film in the region 200 to 300 MeV/c has been obtained from the Goldhaber-Trilling group. The path length is about 10% of K65, but at lower momentum. All strong interactions are being measured so that this energy region may be incorporated into the energy-dependent analysis.

$K^-p \rightarrow \Lambda\pi^+\pi^-$ and $K^-p \rightarrow \Lambda +$ Missing Mass

Terry S. Mast, Angela Barbaro-Galtieri, and Robert D. Tripp

After measurement of most of the events of the type $K^-p \rightarrow \Lambda\pi^+\pi^-$ and a remeasurement of many events with unsatisfactory fits, we have a sample of 10 000 events. The events have been weighted to correct for scanning biases and escape loss, and an analysis of the amplitudes contributing to this reaction is proceeding. Sixty thousand Λ-missing-mass events have been measured, and weights for scanning bias and escape loss have been determined. By use of a maximum likelihood technique the polarization and angular distributions of the $\Lambda\pi^0$ part and those of the $\Sigma^0\pi^0$ part have been determined. The $\Lambda\pi^0$ channel is of particular interest, since it is a pure $I = 1$ state.

Charge-Exchange ($K^-p \to \bar{K}^0 n$) and Elastic ($K^-p \to K^-p$) Reactions

Terry S. Mast, Roger O. Bangerter, Angela Barbaro-Galtieri, and Robert D. Tripp

The momentum range of the incident K^- has been extended up to 430 MeV/c. About 31 000 charge-exchange events have been measured with the Spiral Reader and the Franckenstein, and processed through the programs SIOUX-ARROW. The production angular distribution has been analyzed in terms of Legendre polynomial coefficients (A_ℓ/A_0), and the cross section has been measured. The elastic events are necessary in order to compute the amplitudes of the two isospin channels. Altogether, 60 000 events of this type have been measured and processed. The analysis of contaminations and detection efficiencies has been completed, and the production angular distributions and cross sections have been measured.

Study of $K^-p \to \Sigma\pi\pi$

Roger O. Bangerter, Terry S. Mast, and Robert D. Tripp

We are performing an isotopic-spin analysis of about 1800 events of the types $K^-p \to \Sigma^+\pi^-\pi^0$, $K^-p \to \Sigma^0\pi^+\pi^-$, and $K^-p \to \Sigma^-\pi^+\pi^0$. We have obtained preliminary cross sections for these processes and find them to be strongly coupled to the Y_0^* (1520).

Experimental Test of the $\Delta S = \Delta Q$ Rule in Leptonic Decays of Neutral K Mesons

Bryan R. Webber, Frank T. Solmitz, Frank S. Crawford, Jr., and Margaret Alston-Garnjost

We have studied the time distribution of decays of neutral K mesons produced in the reaction $K^- + p \to \bar{K}^0 + n$. We present independent results based on 81 electronic and 38 muonic decays. Combining these with 133 ambiguous events, we find for the $\Delta S = -\Delta Q$ parameter x the value $Re(x) = 0.25^{+0.07}_{-0.09}$, $Im(x) = 0.00 \pm 0.08$. This value lies about 2.5 standard deviations away from the point x = 0, and to this extent our experiment suggests a violation of the $\Delta S = \Delta Q$ rule. In the course of an investigation of background processes, we identify and measure the rate of the radiative decay $K_S \to \pi^+\pi^-\gamma$. Results of this experiment have been published.[1,2]

Experimental Search for CP-Violating Decay $K_S \to \pi^+\pi^-\pi^0$

Bryan R. Webber, Frank T. Solmitz, Frank S. Crawford, Jr., and Margaret Alston-Garnjost

We have studied the time distribution of the neutral K decays in 53 hydrogen bubble-chamber events of the type $K^-p \to \bar{K}^0 n$, neutral $K \to \pi^+\pi^-\pi^0$. In 20 of these events, the neutral K decay occurs less than four K_S mean lives after production. We find no evidence for a CP-violating amplitude. We point out that a combination of experiments of our type, using an initial $\bar{K}^0$ state, with experiments using an initial K^0 will provide much more information than either type of experiment alone. This is demonstrated when we combine our results with those of an earlier experiment based on 18 K^0 events. Results have been published.[3]

Study of Σ Lifetimes and Branching Ratios

Roger O. Bangerter, Angela-Barbaro Galtieri, Frank T. Solmitz, Robert D. Tripp

Currently there is some disagreement among the published values of the Σ^- lifetime. We are now measuring the lifetimes for both Σ^+ and Σ^-. We are also measuring the branching ratios for $\Sigma^+ \to p\pi^0$ and $\Sigma^+ \to n\pi^+$.

ΣN Interactions

Lawrence K. Gershwin* and Robert D. Tripp

About 75 events each of the reactions $\Sigma^+p \rightarrow \Sigma^+p$, $\Sigma^-p \rightarrow \Sigma^-p$, $\Sigma^-p \rightarrow \Sigma^0 n$, and $\Sigma^-p \rightarrow \Lambda n$ with Σ momenta from 150 to 600 MeV/c are being analyzed. Cross sections for 50-MeV/c intervals and angular distributions for 100-MeV/c intervals are being determined. There does not appear to be any significant resonant structure.

About 1000 events of $\Sigma^-p \rightarrow \Lambda n$ with polarized Σ^- at rest are being studied to measure the Λ polarization.

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1. B. R. Webber, F. T. Solmitz, F. S. Crawford, Jr., and M. Alston-Garnjost, Phys. Rev. Letters 21, 498 (1968) and Phys. Rev. Letters 21, 715(E) (1968).
2. B. R. Webber, F. T. Solmitz, F. S. Crawford, Jr., and M. Alston-Garnjost, Experimental Test of the ΔS = ΔQ Rule in Leptonic Decays of Neutral K Mesons (UCRL-19226 Rev., June 1970), submitted to Phys. Rev.
3. B. R. Webber, F. T. Solmitz, F. S. Crawford, Jr., and M. Alston-Garnjost, Phys. Rev. D1, 1967 (1970).

D. π66 EXPERIMENT

Between February and August 1966, 665 000 pictures were taken of π^+ mesons incident on deuterium in the 72-in. chamber. The beam momentum ranged from 1.1 to 4.2 GeV/c.

π^+d Interactions from 2.7 to 4.2 GeV/c

Orin I. Dahl, Paul L. Hoch, and Donald H. Miller*

We are studying about 20 000 strange-particle production events (with a visible Λ or K^0 decay). (The rest of the 2.7- to 4.2-GeV/c exposure is being analyzed at Purdue and Illinois.) We have completed the measurement of these events on the Spiral Reader and Franckenstein machines, the remeasurement of failing events, and the examination of ambiguous events on the scan table. Problems resulting from the possible assignment of events to the wrong final-state hypotheses and from proton contamination in the π^+ beam have been investigated.

We are investigating the mass difference between the K^{*+} and the K^{*0} using data from this experiment and our previous π^-p exposure.

π^+d Interactions from 1.1 to 2.4 GeV/c

Orin I. Dahl, Donald H. Miller,† and Robert Rader‡

The analysis of strange-particle production has been published,[1] and our data on η and ω production is also to be published.[2] We have also completed the analysis of η' production.[3]

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1. D. W. Davies, M. A. Abolins, O. I. Dahl, J. S. Danburg, P. L. Hoch, J. Kirz, D. H. Miller, and R. K. Rader, Phys. Rev. D2, 506 (1970).
2. J. S. Danburg, M. A. Abolins, O. I. Dahl, D. W. Davies, P. L. Hoch, J. Kirz, D. H. Miller, and R. K. Rader, Production of η and ω Mesons in the Reaction $\pi^+d \rightarrow (p)p\pi^+\pi^-\pi^0$ between 1.1 and 2.4 GeV/c (UCRL-19272, January 1970), to be published in Phys. Rev.
3. R. K. Rader, η' Production in π^+d Interactions from Threshold to 2.4 GeV/c (Ph. D. Thesis), UCRL-19431, December 1969.

E. BP66 EXPERIMENT

Dennis B. Smith

A 72 000-picture proton exposure was made in the Brookhaven National Laboratory 80-in. hydrogen bubble chamber in November 1966. Incident beam momenta were 13, 18, 21, 24, and 28.5 GeV/c, and roughly equal amounts of film were exposed at each of the five momenta. All scanning and measuring of this film have been completed. Topology cross sections have been determined, and a

special ionization scan of approximately 4 000 tracks has been completed for use in the study of the center-of-mass momentum distributions.

For the 40 000 interactions with four or more charged final particles, we used statistical-model parameterizations to fit the longitudinal and transverse center-of-mass momenta distributions. We found that we were able to separate the π^+ from the proton distributions without kinematic fitting of the events. We studied the dependence of the parameters on the incident beam energy and the multiplicity of the interaction. Multiple fireball production was not required by our data. Further study of the charged-pion momentum spectrum is in progress and was reported at the spring meeting of the APS.

A group from Michigan State University, led by Gerald A. Smith, has completed the measurements of 33 000 two-pronged events from this exposure. The measurements were performed at LRL using the Spiral Reader. An analysis of these measurements is under way at Michigan State.[1]

1. Z. M. Ma et al., Phys. Rev. Letters 24, 1031 (1970).

F. ANTIPROTON INTERACTIONS IN DEUTERIUM--ITALIAN COLLABORATION

Margaret Alston-Garnjost, Ronald Huesman, Ronald R. Ross, and Frank T. Solmitz

This experiment is being done by a collaboration of three Italian laboratories (Padua, Pisa, Turin) with LRL physicists.

The CERN 81-cm bubble chamber was exposed to antiprotons with momenta between 1.0 and 1.6 GeV/c, yielding 182 000 events. First and second measurements of these events have been completed on the Spiral Reader, and the data are now being analyzed at LRL and in Italy.

Two papers from this collaboration were presented to the Kiev Conference.[1,2]

1. A Bettini et al., A Study on the Structure in the Antiproton-Neutron Total Cross Section near 1.3 GeV, submitted to 15th Int. Conf. High-Energy Physics, Kiev, USSR, Aug. 1970.
2. A Bettini et al., A Study of the Annihilation $pn \rightarrow \pi^+\pi^-\pi^-$ between 1.0 and 1.6 GeV/c with the Veneziano Model, presented at 15th Int. Conf. High-Energy Physics, Kiev, USSR, August 1970, by M. Cresti.

G. P65 EXPERIMENT

An exposure of the 72-in. hydrogen bubble chamber to protons at 5.5 and 6.6 GeV/c was made in 1965.

p-p Collisions at 6.6 GeV/c

Eugene Gellert, Gerald A. Smith,* and A. Barry Wicklund†

We have examined the $p_\perp^2$ and $p_\parallel$ proton spectra associated with π production and also K production. We found an isotropic $p_\parallel$ distribution, except for the falloff near the kinematic limit. In the $p_\perp^2$ distribution we found a sharp break near $p_\perp^2 \approx 0.2$ (GeV/c).[2] These results have been published.[1]

Nonstrange Interactions in p-p Collisions at 6.6 GeV/c

Eugene Gellert and Gerald A. Smith*

The results of the study of $\eta(549)$ and $\omega(783)$ production in $pp \rightarrow pp\pi^+\pi^-\pi^0$ have been published.[2]

A study of ρ^0 (765) production in $pp \rightarrow pp\pi^+\pi^-$ was concluded. By removing Δ^{++} events, we obtained a 3.4 s.d. ρ^0 signal (and a 1.9 s.d. f^0 signal) and concluded that $\sigma_{\rho^0} = 97 \pm 20$ μb and $\sigma_{f^0} = 31 \pm 13$ μb in $pp \rightarrow pp\,\pi^+\pi^-$. We believe that failure to remove Δ^{++} events is the reason that some authors have had difficulty in seeing or accurately measuring ρ^0 production in this reaction.

These results are being included in a

comprehensive article on $pp \to pp\pi^+\pi^-$ interactions which has been submitted to Physical Review.[3]

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†Argonne National Laboratory, Argonne, IL 60439.

1. M. A. Abolins, G. A. Smith, Z. Ming Ma, E. Gellert, and A. B. Wicklund, Phys. Rev. Letters 25, 126 (1970).
2. E. Colton and E. Gellert, Phys. Rev. D1, 1979 (1970).
3. E. Colton, P. E. Schlein, E. Gellert, and G. A. Smith, The Reaction $pp \to pp\pi^+\pi^-$ at 6.6 GeV/c (UCLA-1036 Rev.), submitted to Phys. Rev.

H. LRL-SLAC EXPERIMENT ON π^-p INELASTIC REACTIONS

Arthur H. Rosenfeld, Gerard Smadja, David J. Herndon, Larry Miller, Ronald Longacre, Bernard Deler,* Paul Söding,† LeRoy R. Price‡ (LRL); David Leith, Roger Cashmore, Anthony Brody,** Ben Shen†† (SLAC)

A systematic study of πN inelastic interactions from threshold up to 2 GeV/c is being carried out. The status as of September 1968 is described in SLAC-PUB-531.[1]

We have added another 250 000 two-prong events from the LRL 72-in. HBC film exposed in 1963. This gives us a total of 600 000 events from the LRL 72-in. HBC, the MURA 30-in. HBC, and the Saclay HBC.

We have developed a general program for maximum likelihood fitting to three-body final states. In the next few months we expect to determine the inelastic branching ratios of the many N^* and Δ resonances with masses below 2 GeV.

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1. A. D. Brody et al., Inelastic Pion-Nucleon Scattering from 720 to 1180 MeV/c (SLAC-PUB-531, 1969).

I. K82 EXPERIMENT

Angela Barbaro-Galtieri, Stephen Derenzo, Stanley M. Flatté, Jerome H. Friedman, Margaret Garnjost, Gerald R. Lynch, Monroe S. Rabin, Frank T. Solmitz, Roland Windmolders,* Philip Davis, Maxine Matison, Norman Uyeda, and Victor Waluch

Scanning and most measuring have been completed on a 35-event/μb, 12 GeV/c, K^+p experiment.

$K^+p \to \pi^+p\,K^0$

More than 1500 events with a visible K^0 have been found. The Bardacki-Ruegg generalization of the Veneziano 5-point function is being tested against this data.

$K^+p \to VP_p$

The reactions $K^+p \to K^*\pi p$, $K\rho p$, $K\omega p$, $K\phi p$ are being compared in an attempt to illuminate relationships expected from SU(3). A double-Regge-pole model is being fit to the data.

Virtual π^+p Scattering

In the reaction $K^+p \to K^*(890)\,\pi^+p$ (9000 events), the π^+p mass spectrum and decay-angle distributions, as a function of momentum transfer from the incoming proton to the π^+p system, are studied for π^+p effective mass less than 2 GeV. The experimental results are compared with the two-parameter Dürr-Pilkuhn OPE model. Discrepancies between experimental results and theoretical behavior are exhibited.

$K\pi$ Scattering

More than 1300 events of the reaction $K^+p \to K\pi\,\Delta^{++}$ are being used to study $K\pi$ scattering through the Veneziano formalism. The theory is unitarized in each partial wave by use of the K matrix formalism.

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J. π82 EXPERIMENT

Angela Barbaro-Galtieri, Stephen Derenzo, Stanley M. Flatté, Jerome H. Friedman, Margaret Garnjost, Gerald R. Lynch, Monroe S. Rabin, Frank T. Solmitz, Fred Buhl, Richard DeCoster, Larry Epperson, Ronald Ott, and Serban Protopopescu

A total of 500 000 pictures with 7-GeV/c π^+ in the 83-in. hydrogen bubble chamber were taken in the first half of 1969.

All events except 2-prongs have been measured at least once, and the 2-prong measurements will begin in October 1970.

A_2 Mass Spectrum

A paper is being submitted to Physics Letters showing the mass distributions for 940 $A_2^+ \rightarrow \pi^+\pi^+\pi^-$ events with resolution HWHM = 6.7 MeV, 130 $A_2^+ \rightarrow K^+\bar{K}^0$ events with resolution HWHM = 3.8 MeV, and 190 $A_2^+ \rightarrow \pi^+\eta$ events with resolution HWHM = 9.2 MeV. A Breit-Wigner resonance formula fits the data; and in all cases, whether fit simultaneously or separately, the distributions give poorer fits to a two-parameter double-pole hypothesis. Two coherent resonances with arbitrary amplitudes and phase can easily fit the data.

A_2 Branching Ratios

With approximately 1400 events of the type $\pi^+p \rightarrow A_2^+p$, the branching ratios into 3π, $K\bar{K}$, and $\eta\pi$ have been determined for our experiment. Since there has been structure reported in the A_2 region, the branching ratios must be regarded at the moment as information to be used in understanding structure, rather than basic physical information.

A_2 Spin-Parity

The spin parity structure of the A_2 is being studied in three decay modes: $\pi^+\pi^+\pi^-$, $K\bar{K}$, and $\eta\pi$.

ρ-ω Interference

More than 10 000 events of the type $\pi^+p \rightarrow \rho^0\Delta^{++}$ and 2000 events of $\pi^+p \rightarrow \omega\Delta^{++}$ are being studied in an attempt to determine the relative phase and coherence of ρ and ω productions.

f^0 Mass Spectrum

More than 5000 events of the reaction $\pi^+p \rightarrow f^0\Delta^{++}$ have been investigated for structure in the f^0 mass spectrum and in the f^0 decay-angle distributions as a function of mass. The resolution HWHM is 7 MeV. No obvious structure is seen.

1. M. Alston-Garnjost, A. Barbaro-Galtieri, W. F. Buhl, S. E. Derenzo, L. D. Epperson, S. M. Flatte, J. H. Friedman, G. R. Lynch, R. L. Ott, S. D. Protopopescu, M. S. Rabin, and F. T. Solmitz, A_2 Mass Spectrum in 7 GeV/c π^+p Interactions (UCRL-20129, October 1970), submitted to Physics Letters.

K. BACK-SCATTERED LASER BEAM AT SLAC

Kenneth Moffeit, William Podolsky, Monroe Rabin (LRL); Roger Gearhart, Paul Klein, Joseph Murray, and Charles Sinclair (SLAC)

A unique photon beam[1] has been developed and used with the SLAC 82-in. hydrogen bubble chamber. This variable high-energy beam is 90% polarized (linear or circular) and virtually monochromatic. It is generated by back-scattering ruby laser light from the primary electron beam at SLAC. The energy can be varied from 0.5 to 7 GeV. Full-width resolution (80% of the photons) is 3% at 800 MeV, 7% at 3 GeV, and 10% at 5 and 6.5 GeV.

The useful energy of the photon beam has recently been extended to 10 GeV by

frequency-doubling the ruby laser light using a KDP crystal. The full-width resolution of the beam is 15% at 10 GeV.

1. C. K. Sinclair, J. J. Murray, P. Klein, and M. Rabin, IEEE Trans. Nucl. Sci. 16, 1065 (1969).

L. PHOTOPRODUCTION EXPERIMENTS

Kenneth Moffeit, William Podolsky, Monroe Rabin, and Arthur Rosenfeld (with experimenters from SLAC, U. C. Berkeley, Tufts University, and LIBHE, Brussels)

The SLAC-Berkeley-Tufts collaboration has taken 1 230 000 pictures in the SLAC 82-in. bubble chamber with the Compton backscattered laser beam. The exposures were:

Deuterium:	0.8, 3, 5, 6.5 GeV	50 000 pictures
Hydrogen:	1.5 GeV	20 000 pictures
	3 GeV	300 000 pictures
	5 GeV	460 000 pictures
	10 GeV	400 000 pictures

Scanning and preliminary analysis on all the film are just about complete and results have been published on the total γp cross section.[1]

Polarization of the incident photon beam allows us to separate Pomeron exchange (via the vector-dominance model) from other particle exchanges. Using this information, we have studied ρ^0,[2, 3, 4] ω, and Δ^{++}[5] photoproduction in hydrogen at 3 and 5 GeV. Results at 10 GeV should be ready in several months.

1. J. Ballam et al., Phys. Rev. Letters 23, 498 (1969) and Phys. Rev. Letters 23, 817(E) (1969).
2. H. H. Bingham et al., Phys. Rev. Letters 24, 955 (1970).
3. J. Ballam et al., Phys. Rev. Letters 24, 960 (1970) and Phys. Rev. Letters 24, 1467(E) (1970).
4. J. Ballam et al., Phys. Rev. Letters 24, 1364 (1970).
5. H. H. Bingham et al., Δ Production via $\gamma p \rightarrow \Delta\pi$ by Linearly Polarized Photons at 2.8 and 4.7 GeV (SLAC-PUB-766, 1970), submitted to Phys. Rev. Letters.

II. ACCELERATOR EXPERIMENTS USING SPARK CHAMBERS

A. PROGRAM IN COLLABORATION WITH MOYER-HELMHOLZ GROUP

Orin I. Dahl, Morris Pripstein, and Michael Wahlig

A series of spark-chamber experiments at the Bevatron has been undertaken to study various neutral final states in $\pi^- p$ interactions.

Neutral Decay Modes of the η Meson

In the Fall of 1968 we completed a Bevatron experiment to measure the branching ratios of the various neutral decay modes of the η meson in a study of the reaction $\pi^- p \rightarrow n\eta$, just above threshold, where the cross section for this reaction is maximum. The reaction was identified by detecting all the final-state particles. The detection equipment consisted of a set of very large spark chambers to detect γ rays and a set of neutron counters to measure the neutron angle and time of flight from the liquid-hydrogen target. The 20 neutron counters were mounted in a ring at a polar laboratory-system angle of 13.2 deg. The spark chambers were between 7 and 8 radiation lengths thick, and formed five of the six faces of a cube, with the target at the center, so that the solid angle for detection of γ rays from the decay of the η meson was large.

In the experiment, we took a total of approximately 250 000 pictures, of which 40 000 contain events from the reaction $\pi^- p \rightarrow \pi\eta$; the rest include important information about various types of background.

We have scanned and measured about 25% of the data, using the automatic SASS scanning and measuring device. In addition, a portion of the data has been scanned by a team of scanning personnel. Results, based on the above sample, have been reported.[1]

Search for the Decay $N^*(1680) \rightarrow n\eta$

In March 1969 we completed the data-taking phase of this second experiment at the Bevatron, using exactly the same beam and equipment (but suitably rearranged in position) as described in the first experiment above.

This experiment is a search for the hitherto undetected $n\eta$ decay mode of the two $N^*_{1/2}$ resonances with masses about 1680 MeV, and with spin-parity quantum numbers of $5/2^+$ and $5/2^-$, respectively. For this purpose, we have measured the differential cross section for the reaction $\pi^- p \rightarrow n\eta$ at six different π^- beam laboratory momenta: 880, 930, 980, 1030, 1080, and 1130 MeV/c. About 500 000 pictures have been taken, which contain about 1000 events of the final state $n\eta$, $\eta \rightarrow \gamma\gamma$ at each of these momenta. A partial-wave analysis of these angular distributions will determine the magnitude of the $n\eta$ contribution to these spin-5/2 resonances.

The spark-chamber pictures are presently being scanned and measured using the SASS device, with a portion of the data also being scanned by our scanning personnel.

Neutral Diboson Experiment

With the same personnel and much of the same equipment as in the preceding spark-chamber experiments, we have performed an experiment at the Bevatron to study the reaction $\pi^- p \rightarrow n\pi^0 \pi^0$ between 1.5 and 2.5 GeV/c. The principal purposes of the experiment are to analyze the $\pi^0\pi^0$ system in a search for scalar mesons and to measure the π-π phase shifts. In addition, we have taken data to measure the charge-exchange differential cross section.

We have collected about 500 000 pictures under various operating conditions. Of these, approximately 75 000 four-shower and 45 000 three-shower events were collected for purposes of studying the final state $n\pi^0\pi^0$. In addition, approximately 30 000 two-shower charge-exchange events were collected. Preliminary results have been presented.[2]

1. T. B. Risser, Neutral Decay of the η^0 Meson (Ph. D. Thesis), UCRL-20039, August 1970.
2. M. Pripstein, Bull. Am. Phys. Soc. 15, 766 (1970).

B. DEUTERON MISSING-MASS EXPERIMENT

M. A. Abolins,* R. Graven, R. McCarthy, G. A. Smith,* L. H. Smith,† and A. B. Wicklund‡

This experiment has been completed and published.[1]

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†Space Sciences Laboratory, University of California, Berkeley, CA 94720.
‡Argonne National Laboratory, Argonne, IL 60439.
1. M. A. Abolins, R. Graven, R. McCarthy, G. A. Smith, L. H. Smith, A. B. Wicklund, R. L. Lander, and D. E. Pellett, Phys. Rev. Letters 25, 469 (1970).

III. HIGH-ALTITUDE PARTICLE PHYSICS AND COSMIC-RAY EXPERIMENTAL FACILITY

A. BALLOON FLIGHT PROGRAM

Luis W. Alvarez, Andrew Buffington,* Philip M. Dauber,† Lester J. Lloyd‡ Richard A. Muller,* Lawrence H. Smith,* and Michael A. Wahlig

During the past year, we have successfully flown our first experimental cosmic-ray gondola on a balloon flight, and have laid the foundation for future satellite experimentation.

The balloon flight carried our Small Superconducting Magnet (SSCM) gondola system. This system included a superconducting magnet, optical spark chambers, and plastic and CsI scintillation counters. The object of this flight was the determination of the momentum spectrum from 5 to 100 GeV of individual elements from helium to the iron group. The charge determination was made by pulse-height analysis of the signals from the scintillation counters.

The entire system was contained within an 8-ft-diameter pressurized sphere, and had a total weight of 4000 lb.

The experimental gondola was flown successfully from Palestine, Texas, on September 18, 1970. The 20-million-cubic-foot balloon reached a float altitude of 119 000 feet (4.8 g/cm^2 residual atmosphere). At float, data were taken for 6 hours with the magnet charged. The magnet was discharged, and then 1 hour of magnet-off calibration data were taken. Only slight damage to the equipment resulted from the parachute descent and the gondola-recovery operation.

Prior to this flight, we required that the balloon-parachute-rigging system be certified via a successful test flight using a dummy gondola. We had contracted the Air Force Cambridge Research Laboratory (AFCRL) to fly our package from Chico, California. After three unsuccessful attempts to fly our test flight, during December 1969 and January 1970, we cancelled our contract with AFCRL and contracted to fly with the National Center for Atmospheric Research (NCAR) which operates a launch facility at Palestine, Texas.

In March, NCAR successfully flew our test flight from Palestine. The experimental gondola was then transferred from Chico to Palestine. However, the superconducting magnet suffered some damage to its vacuum system during shipment and had to be sent to Berkeley, repaired, and returned to Palestine.

The experimental gondola was flown for the first time on July 10. The launch was fine, but soon afterwards the batteries powering the experimental equipment started to fail. By the time float altitude was reached, the battery voltages were too low for useful operation. No data were obtained. However, the parachute descent and landing, and the recovery operation, produced such slight damage to the equipment that we were soon able to re-fly the gondola. On September 18, the gondola was flown again, resulting in the successful experiment described above.

We have been pushing the state of the art in cryogenic spectrometers for several years now, and this flight represented a significant advance in cosmic-ray-physics technique. The data from this flight should provide valuable information on intra-galactic propagation.

Looking toward future cosmic-ray experimentation utilizing satellites, we have proposed an experiment for the High Energy Astronomical Observatory (HEAO) series of satellites. This experiment would make use of an arrangement quite similar to that of our present balloon experiments, but on a somewhat larger scale. Included would be a superconducting magnet, wire chambers, scintillators with pulse-height-analysis capability, and a total absorption shown counter (TASC). The primary experiment would be the determination of the momentum spectrum of electrons and positrons. Part of the experimental running time of approximately one year would be used for secondary experiments, for which the experimental setup is identical but the triggering criterion is different. These experiments would include a search for antihelium nuclei, and determination of momentum spectra of individual elements from hydrogen to iron.

This HEAO proposal has already passed several preliminary screenings. If given final approval, it will probably be on board the 2nd or 3rd satellite in this series, and will be launched in 1976 or 1977.

The analysis is being started on the data accumulated during the recent balloon flight. We anticipate the next balloon flight during spring or summer 1971; its exact configuration will depend upon the results of the present data.

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‡Decision Inc., 5601 College Ave., Berkeley, CA 94618

B. EMULSION SPECTROGRAPH PROGRAM

Spark Chambers-Emulsion Systems

Philip M. Dauber,* Lawrence H. Smith,† and Michael A. Wahlig

This part of the program has been completed and has been submitted (January 1970) and accepted for publication in Nuclear Instruments and Methods under the title "Track-Finding in Emulsion Plates with the Air of High Resolution Spark Chambers."[1]

Granite Stage

Margaret Alston-Garnjost and Robert Smits

A measuring stage has been constructed with 0.5-by-0.5-meter travel, laser-interferometer readout with 1/12 mm least count, and computer control. We have used this device to test the feasibility of scanning and measuring large emulsion plates. A report of this work is nearly complete.

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†Space Sciences Laboratory, University of California, Berkeley, CA 94720.
1. P. M. Dauber, L. H. Smith, and M. A. Wahlig, Nucl. Instr. Methods 84, 199 (1970).

C. LRL-SLAC COSMIC RAY EXPERIMENT

Stanley M. Flatté, Richard DeCoster, M. Lynn Stevenson, in collaboration with William Toner and Ted Zipf of SLAC

Over 1.5 million pictures of cosmic-ray muons in spark chambers have been gathered. The low-momentum cutoff is about 5 GeV/c, and the angular acceptance covers 50° to 90° zenith angle.

The geometry-time factor for the experiment is approximately 2×10^9 cm^2-sr-sec. More than 500 events with momentum above 1000 GeV/c have been found. The muons traverse a 27 kg-m magnet, and the measurement error on the bend angle corresponds to the bend of a 2000-GeV/c particle. Analysis of the momentum spectra and angular distributions is under way.[1]

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1. R. DeCoster, S. Flatté, M. L. Stevenson, W. T. Toner, and T. Zipf, SLAC-LRL Meson Spectrometer (SLAC-PUB-687, November 1969), presented at 11th Int. Conf. Cosmic Ray Physics, Budapest, Hungary, 1969.

IV. SEARCH FOR MONOPOLES

Luis W. Alvarez, Philippe Eberhard, and Ronald R. Ross

Results from the search for monopoles in the lunar sample of Apollo XI have been published.[1] A description of the monopole detector has been written.[2] The further search for monopoles in lunar samples has been postponed to April 1971 due to the accident during the Apollo XIII flight. A proposal to search for monopoles at NAL has been accepted.

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1. L. W. Alvarez, P. H. Eberhard, R. R. Ross, and R. D. Watt, Science 167, 701 (1970) and Proc. Apollo XI Lunar Science Conference 3, 1953 (1970).
2. L. W. Alvarez, M. Antuna, Jr., R. A. Byrns, P. H. Eberhard, R. E. Gilmer, E. H. Hoyer, R. R. Ross, H. H. Stellrecht, J. D. Taylor, and R. D. Watt, A Magnetic Monopole Detector Utilizing Superconducting Elements (UCRL-19756, April 1970), submitted to Rev. Sci. Instr.

V. DEVELOPMENT OF DETECTORS USING LIQUIFIED NOBLE GASES

Luis W. Alvarez, Stephen E. Derenzo, Richard A. Muller,* Dennis B. Smith, Gerard Smadja, and Haim Zaklad

In an effort to develop a liquid-filled high-resolution wire chamber we are studying the multiplication of ionization electrons in liquid argon and liquid xenon near the surface of fine wires from 2.5 to 13 μ in diameter and near

etched tungsten tips from 1 to 2 μ in diameter. The pulses are typically 0.5 V in size (on a 100 pF load) and have a rise time of 5 to 10 μsec in liquid argon and < 20 nsec in liquid xenon.

Using a 3.5-μ tungsten wire in very pure liquid xenon, we have obtained a charged particle detection efficiency greater than 20% and a time resolution of ± 100 nsec. In addition, a 3.5-μ wire in liquid xenon acts as a dc spark counter, delivering pulses 100 nsec wide and 5 to 10 V high into a 50-ohm load. We find that when somewhat larger wires or liquid argon is used, electron evalanching is unreliable and occurs at places only sparsely distributed along the length of the wire.

We will soon be using 2 μ wide conducting strips attached to a dielectric substrate and separated from a flat cathode by 100 μ of liquid xenon. If necessary, rows of sharp points can be deposited on the conducting strips. In such a geometry, a space resolution of 10 μ and a time resolution of 10 nsec does not appear unreasonable.

Several reports have been published on this experiment.[1-4]

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1. S. E. Derenzo, R. A. Muller, R. G. Smits, and L. W. Alvarez, The Prospect of High Spatial Resolution for Counter Experiments — A New Particle Detector Using Electron Multiplication in Liquid Argon (UCRL-19254, October 1969), in National Accelerator Laboratory 1969 Summer Study Report SS-154, Vol. III, pp. 79-102.
2. S. E. Derenzo, D. B. Smith, R. G. Smits, H. Zaklad, L. W. Alvarez, and R. A. Muller, Recent Developments in High-Resolution Noble Liquid Counters (UCRL-20118), National Accelerator Summer Study Report SS-181, July 1970.
3. H. Zaklad, Integrated Circuit Readout for Closely Spaced Wire Arrays (UCRL-20123), National Accelerator Laboratory Summer Study Report SS-181, July 1970.
4. R. A. Muller, S. E. Derenzo, R. G. Smits, H. Zaklad, and L. W. Alvarez, Particle Detectors Based on Noble Liquids (UCRL-20135), in Proc. Int. Conf. Instrumentation for High Energy Physics, Dubna, 1970.

VI. PARTICLE DATA GROUP

Angela Barbaro-Galtieri, Stephen E. Derenzo, LeRoy R. Price,* Alan Rittenberg, Arthur H. Rosenfeld, Odette Benary†

This group is involved in three major activities: 1) The periodic issuance of "Reviews of Particle Properties," both in Reviews of Modern Physics and as the unpublished report, UCRL-8030, printed at LRL and at CERN. 2) The printing of books of particle cross-section data, under the designation UCRL-20 000, again at LRL and at CERN. 3) The development of an improved overall computer system for the storage, retrieval, and output of these data on particle properties and cross sections.

Particle Properties

The January 1970 edition of "Reviews of Particle Properties" was again published in Rev. Mod. Phys.[1] A slightly improved format and arrangement, together with more detailed reviews and summaries of experimental inconsistencies, were designed to improve the usefulness of the report. The next edition (August 1970) will be published in Physics Letters.

Cross-Section Compilations

The second in the series of UCRL-20 000 reports on cross-section data, this one concerned with YN (hyperon-nucleon) reactions, was issued in January 1970.[2] Work is in progress for the third report, on NN (nucleon-nucleon) scattering, due about August 1970.

A report on πN partial-wave amplitudes was produced in February 1970.[3] This is the beginning of a series, designated UCRL-20 030, related to the cross-section compilation reports.

Work was begun on rewriting the computer program which produces the plots appearing in the UCRL-20 000 reports.

Overall Data Storage, Retrieval, and Output System

As the result of the loss of a programmer to work on this general system, little progress was made. However, we do plan to utilize a rudimentary text-entry system developed by the Math and Computing group at the lab. We hope in this way to gain some experience in this area, so that when we return to our own project (in about two months) we may avoid some of the pitfalls discovered.

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†University of Tel-Aviv, Ramat Aviv, Tel-Aviv, Israel.

1. A. Barbaro-Galtieri et al., Rev. Mod. Phys. 42, 87 (1970).
2. O. Benary, N. Barash-Schmidt, L. R. Price, A. H. Rosenfeld, and G. Alexander, A Compilation of YN Reactions (UCRL-20000 YN, January 1970).
3. D. J. Herndon, A. Barbaro-Galtieri, and A. H. Rosenfeld, πN Partial Wave Amplitudes: A Compilation (UCRL-20030 πN, February 1970).

VII. DATA-REDUCTION OPERATIONS

Edward H. Hoedemaker

A. EFFORT

During this eight-month period, the manpower level of the Scanning and Measuring Payroll (Account No. 9207) averaged 45.4 full-time equivalents, 29% below the same period last year.

B. SCANNING

Four experiments required extensive scanning during this period: π82, LASER, Nππ, and CR 69. The table below illustrates the distribution of effort on these and other experiments, and gives the numbers of frames scanned in each case.

Scanning Distribution

Experiment name (number)	Frames of first production scan	Frames of second and third production scans	Scan effort (h)
K82 (30)			
Miscellaneous			263
π82 (32)			
1st scans	217 326		1126
2nd and 3rd scans		149 866	848
Miscellaneous			3168
η86 (34)			
1st scan	12 666		255
Miscellaneous			274
N* Decay (35)			
1st scan	23 520		469
Miscellaneous			116
Laser (37)			
1st scan	219 208		1120
2nd scan		193 254	994
Miscellaneous			1043
CR69 (42)			
1st scan	979 750		3252
2nd scan		234 109	789
Miscellaneous			1108
Nππ (43)			
1st scan	111 121		2863
Miscellaneous			869

C. MEASURING

Altogether 486 699 events were measured between November 1, 1969, and June 30, 1970. Spiral Reader I was off the air for 27 weeks for modification, and consequently contributed only 60 000 events to this total.

Two Franckensteins were used (at roughly 20% of capacity) to measure 12 661 events. MP2B was rebuilt and a small (NOVA) computer was added to gain speed and accuracy. It should be operational in mid-October.

The breakdown below shows the number of events measured on each machine.

Breakdown of measurements by machine used.

Franckensteins	Events	Measuring hours
IIC	4 030	608
IID	8 631	1 905
All MP's	12 661	2 513
Spiral Readers		
SRI	60 130	592
SRII	336 308	4 383
Both SR's	396 438	4 975
SASS	77 600	814
All machines	486 699	8 302

Breakdown of measurements by experiment.

Name (number)	Description	Number of events
Bubble chamber experiments		
LRL/SLAC (27)	π^-p, 82-in.	31 113
K65 (21)	K^-p, 25-in.	16 271
K82 (30)	K^+p, 82-in.	25 190
π82 (32)	π^+p, 82-in.	318 421
Laser (37)	γp, 82-in.	13 808
Miscellaneous		4 296
	Total	409 099
Spark chamber experiments		
η86 (34)	π^-p, optic., n TOF	16 757
N^* Decay (35)	π^-p, optic., n TOF	31 543
$N\pi\pi$ (43)	π^-p, optic., n TOF	29 300
	Total	77 600
	Total for group	486 699

VIII. PROGRAMMING EFFORT

PERSONNEL

Barrie Pardoe
(supervisor of Group A programmers)

U. Arkadir
J. H. Burkhard
R. W. Casey
B. J. Cottrell
O. I. Dahl
N. L. Gould
M. Hoffman
M. S. Hutchinson
D. Iverson
W. O. Koellner
M. Leavitt
E. G. Lieberman
S. W. Reynolds
J. J. Wilson
E. A. Romascan

SUMMARY

From November 1969 through June 1970, the programming group continued the essential task of maintaining and developing the larger programs used in the group's physics program. As this work is fairly routine and aims mostly at making the programs more efficient, it need not be described further.

For the first time, and in conjunction with the Computer Science Department at U. C. Berkeley, the group undertook to train 3 selected undergraduates in computer-graphics techniques.

Bubble Chamber Programs

Changes were made to the program which filters spiral-reader measurements (POOH) to improve the handling of charged vertex-connecting tracks and to prevent tracks from secondary vertices being associated with the primary vertex.

An experimental version of POOH is now available which eliminates the need to re-process events failing because a proper track has not been found in a certain view. Instead, tracks found in the other views are used to point to the missing track.

Conversion of the kinematic-fitting program RESQUAW to a compiler generating more efficient code resulted in a reduction of execution time by 15 to 20%.

The post-kinematic processing program ARROW has now been superseded by the program KIOWA which provides all the features of ARROW but is more powerful and efficient.

Spark Chamber Programs

The program DHARMA which identified showers from spark-chamber film measured on the SASS[1] system is now in production. There are two versions: the first identifies 2-shower events and the second, using additional information provided by scanners, identifies multishower events.

Development of the programs for the Cosmic-Ray-Angular-Distribution experiment continues.

General Support

An assembler and a symbolic debugging package were written for the NOVA computer which will drive the Mark-II Franckenstein, and it is expected that measuring will begin within the next three months.

In a similar vein, tape-transport routines and various debugging and testing programs were written for the PDP-9 computer to control the Spiral Reader being built for the University of Tennessee; this project was completed.

The PDP-8 program to drive the granite-stage measuring machine was completed.

Fairly good use is now being made of the IBM-1360 photodigital storage system as a result of the group's providing suitable routines. Work is continuing on the development of the system to allow entire experimental libraries to be stored on the device.

Recent Programming Notes and UCRL Reports

Publication Number	Date	Author(s)	Title
UCRL-19429	November '69	B. Pardoe.	On Finding Prime Numbers
P-195	October '69	W. Koellner	GROUP A--Mass Storage Usage
P-196	December '69	B. Pardoe	CLEANUP
P-197	December '69	B. Cottrell	CHANGE TO MERGE-SELECT PROGRAM Merge Select Input Deck
P-198	January '70	W. Koellner	MSELECT--Group-A Mass Storage Skelm and Select Program
P-199	January '70	W. Koellner	OPTIME SAGE Fitting Program Using Sage II
P-200	February '70	J. Burkhard	CDC-6600 ASSEMBLER for the NOVA COMPUTER
P-201	February '70	M. Hutchinson	CCSCB--A subroutine to Plot Greek and Roman Characters and Mathematical Symbols on the Cal-Comp Plotter
P-202	February '70	J. Friedman	A SAGE Users Guide to SAGE II
P-203	February '70	G. Armstrong	I/O PACKAGE
P-204	February '70	B. Cottrell	I/O ROUTINES, 6600
P-205	May '70	M. Alston-Garnjost . .	SIOUX AND RESQUAW FOR K82 and PI82
P-206	May '70	R. Carlson	STEEP--Spiral Reader Optical Calibration Program
P-207	July '68	C. Gimber	VOPUS--Ray Track for Vista
P-208	June '70	E. Lieberman	A User's Guide to SRT SPIDER, the Calibration Program for the Tennessee Spiral Reader

1. Donald H. Zurlinden, Computer-Controlled Data Reduction of Spark Chamber Film (UCRL-17695, Aug. 1967).

EXPERIMENTAL PHYSICS

Kenneth M. Crowe and Donald H. Miller in charge

PRECISION MEASUREMENT OF THE MAGNETIC MOMENT OF THE MUON

Kenneth M. Crowe, Michael Delay,* John F. Hague,* Joseph E. Rothberg,* Alexander Schenck,* David L. Williams,* Robert W. Williams,* and Kenneth K. Young*

Precise determination of the muon magnetic moment has been published.[1] The result for its ratio to the proton moment $\mu_\mu/\mu_p = 3.183347(9)$ or 2.8 ppm is better by a factor of five than previous results and about half the error planned initially. The chemical shift correction in water was checked by using pure water, 0.1 M NaOH, and malononitrile as muon stopping targets. There was no significant different between these targets, which suggests that the "Ruderman" correction is not important. The results compare favorably with previous measurements and with the recent series of muonium hyperfine splitting frequency determinations. The combination of the Yale and Chicago results with the magnetic moment yields a fine-structure constant in excellent agreement with the recent Josephson-effect value.

*University of Washington, Seattle, Washington.

1. K. M. Crowe, M. Delay, J. F. Hague, J. E. Rothberg, A. Schenck, D. L. Williams, and K. K. Young, Phys. Rev. Letters 25, 628 (1970).

MUON DEPOLARIZATION STUDIES

Kenneth M. Crowe, Edmund Geneux,* Richard Johnson, Alexander Schenck,† David Williams,† and Robert Williams†

As an outgrowth of the magnetic-moment measurement, measurements related to the behavior of muons in condensed matter are being made. The slow relaxation phenomenon has been studied for various solids and liquid solutions.[1] For example, the anisotropy of the transverse relaxation time for muons stopping in a single crystal of gypsum has been observed, and a beating in the precession pattern can be explained quantitatively by using the data for the NMR spectrum for protons, if one assumes that the muons occupy the same sites as the protons in the crystal.

By introducing paramagnetic ions into water --i.e., Mn^{++}, Fe^{+++}, and Gd^{++}--one can observe spin relaxation, which can be likewise explained by exploiting this analogy. Since rapid depolarization corresponds to wide NMR lines, our measurements can be used to extend the T_2 measurements to high concentrations. We observe several nonlinear effects as a function of concentration. For example, in $MnCl_2$ the contact interaction appears to be quenched, presumably due to a variation in the electron spin correlation time. The theory of this process is being studied. For Fe^{+++} ions we see evidence for anion dependence, which is also very sensitive to the temperature of the liquid. Many other physical chemical effects are being considered.

Precession of muons stopped in lead near the superconducting critical temperature gives clear evidence for the Meissner effect. The muons stop their precession as the field is expelled from the interior of the superconducting lead.

Most insulating solids studies show relaxation phenomena.[2]

Finally, the fast depolarization of muons which determines the observed asymmetry depends on the environment. We observe that in strongly oxidizing aqueous solutions of HNO_3, $AgNO_3$, $Fe(NO_3)_3$, etc. and I_2 dissolved in methyl alcohol the asymmetry rises from approximately 50% to near 100% of the maximum possible as the concentration increases. The hot

chemistry and thermal reactions (of muonium) are presumably responsible for terminating the rapid muonium depolarization mechanism that occurs in pure water and alcohols.

*University of Washington, Seattle, Washington.
†University of Genève, Genève, Switzerland.
1. A. Schenck, Phys. Letters 32A, 19 (1970).
2. A. Schenck, D. Williams, K. Crowe, E. Geneux and R. Johnson, Bull. Am. Phys. Soc. 15, 1518 (1970).

RADIATIVE CAPTURE EXPERIMENTS

James Bistirlich, Kenneth M. Crowe, Jerome Helland, and Peter Truoel

The study of π capture at rest in nuclei leading to high-energy γ rays has been actively pursued during this period. Data taken with the photographic spark chamber have been analyzed for H, ^{4}He, ^{12}C, ^{16}O, ^{40}Ca, ^{24}Mg, H_2O, and CH_2, and results for ^{4}He and ^{12}C published.[1,2] Results for the others are being prepared for publication. The preliminary run established solidly the "fine" structure in the spectrum due to the final nuclear states produced, and verified that in addition a continuous "background" was present owing to direct capture on moving protons. Quantitative observation of branching ratios to the ground state and excited states as well as the total rate has, we hope, stimulated calculations to verify which model best describes the observations.

Further work using magnetostrictive readout wire chambers facilitates data reduction and analysis of the spectra. In addition, we plan to use ^{2}H, ^{3}He and ^{6}Li, ^{7}Li as well as O_2 for corresponding information about the nuclear final states, such as remeasurement of the nn scattering length and exploration of the three-particle states (pnn). Neutron detectors are added to gather data on the angular correlation for the associated neutron which is produced to check the "direct" process. Data taking should begin in January 1971.

1. J. Bistirlich, K. M. Crowe, A. S. L. Parsons, P. Skarek, and P. Truoel, Phys. Rev. Letter 25, 689 (1970).
2. J. Bistirlich, K. M. Crowe, A. S. L. Parsons, P. Skarek, P. Truoel, and C. Werntz, Phys. Rev. Letters 25, 950 (1970).

A STUDY OF $\pi^- p \rightarrow \gamma n$ FOR CENTER-OF-MASS ENERGIES 1370 TO 1600 MeV

Kenneth M. Crowe, Anthony Fainberg, A. S. L. Parsons, Peter Truoel, Roy P. Haddock,* B. M. K. Nefkens,* L. H. Verhey,* Allan Weiss,* and Michael E. Zeller*

Differential cross sections for $\pi^- p \rightarrow \gamma n$ for pion momenta between 500 and 900 MeV/c and photon c.m. angles between 45 and 150 deg were measured at the Bevatron during 1969. The apparatus was the same as that of Berardo et al.[1] A least-squares kinematical analysis achieves optimum signal extraction from the large charge-exchange background. The data are also used to determine the charge-exchange cross sections. Results are compared with existing data and with the CERN phase-shift predictions to check the incoming pion flux normalization.

Results will be presented at the Western APS Meeting at Stanford in December 1970. The data will be used to clarify the isospin decomposition of neutral pion-nucleon resonances and as a test of the time-reversal invariance by comparison with data for the inverse reaction.

*University of California—Los Angeles, California.
1. P. A. Berardo, R. P. Haddock, B. M. K. Nefkens, L. J. Verhey, and M. E. Zeller, A. S. L. Parsons, and P. Truoel, Phys. Rev. Letters 24, 419 (1970).

$K^0_{\mu 3}$ CHARGE ASYMMETRY

D. H. Miller, R. J. Budnitz, W. N. Ross, R. L. McCarthy, and J. H. Brewer

Apparatus has been set up at the Bevatron for a measurement of the relative decay rates of the K^0_L meson to π, μ, and ν: R = Rate ($K^0_L \rightarrow \mu + \nu$)/Rate ($K^0 \rightarrow \pi^+ \mu - \nu$). If R differs from unity, it is evidence for a CP violation in the decay.

About 150 scintillation counters are set up around a large (52-in. gap, 8000-G) magnet. All information for each event is transferred on line to a PDP-9 computer for analysis.

Until June 1970, the apparatus was being tested and small systematic errors reduced. The experiment is to accumulate about 10 million events and to measure R to within $\approx \pm 0.08\%$. (The best measurement so far gave R = 1.0081 ± 0.0027.)

NUCLEAR EMULSION GROUP

Harry H. Heckman in charge

TEMPORAL BEHAVIOR OF INNER-BELT PROTONS

Harry H. Heckman and Peter J. Lindstrom*

The time variation in the flux of energetic trapped protons (E > 57 MeV) at low satellite altitudes are due principally to the solar cycle (11-yr period) and semiannual changes in the atmospheric density. We are now incorporating an up-dated and improved atmospheric model[1] into the continuity equation that describes the temporal behavior of the inner-belt protons. This model parametrizes the solar cycle, semiannual, diurnal, seasonal, and geomagnetic changes of the atmosphere in terms of a "temperature," facilitating computational procedures. We have also begun an examination of the effects of multiple scattering of the trapped protons in the region of low mirror-point altitudes as a mechanism of pitch-angle diffusion. The latter study is an attempt to account for the strong altitude dependence of the proton source-function suggested by our observations.

*Space Sciences Laboratory, University of California, Berkeley.

1. L. G. Jacchia, New Static Models of the Thermosphere and Exosphere with Empirical Temperature Profiles, Smithsoian Astrophysical Observatory Special Report No. 313.

PARTICLE IDENTIFIER

Harry H. Heckman and Douglas E. Greiner*

As described previously, the particle identifier we have developed in cooperation with the U. C. Space Sciences Laboratory† is a linear array of eight silicon detectors, which provides dE/dx information as a function of range. A chi-square analysis of the pulse information yields energy and mass information to better than ± 1% and 0.1%, respectively. The identifier is being applied to a search for the presence of trapped hydrogen and helium isotopes in the inner radiation belt.

The data from our first rocket experiment (carried out at Natal, Brazil, September 1969) have been analyzed. We have obtained: a) the flux vs altitude for protons in the energy intervals 30 to 60 MeV and 60 to 90 MeV; b) east-west asymmetries in the flux as a function of pitch angle; and c) an upper limit of the relative abundance (1%) of trapped particles, $m \geqslant 2$. In c), our data were limited by statistics and noise problems in the rocket telemetry, owing to failure of another experiment.

Utilizing these data and the experience gained in this experiment, we are now constructing two improved flight instruments to be launched to ≈ 1000 km altitude from Natal in September 1970.

*Space Sciences Laboratory, University of California.

†Work performed at UCSSL under NASA contract NAS 9-5249.

RIGIDITY SPECTRA OF HEAVY COSMIC-RAY IONS USING A SUPERCONDUCTING MAGNET

Harry H. Heckman, Robert L. Golden,* and Clifford L. Deney*

The scanning and analysis of the data obtained in the balloon flight of August 1969 from Palestine, Texas, are in progress. Scanning of the 4×4×6-in. emulsion stack for incident heavy ions has been completed. Rescans for efficiency checks are now being done. Charge measurements for the ions that traverse the spectrometer, using the TV microscope, are also in progress. Measurements of the rigidity of the incident ions (performed at MSC, Houston) are proceeding satisfactorily. The alignment of the emulsions in the magnetic fields has been defined to ± 2 microns, as of this time, allowing the rigidity spectra to be measured to an upper limit of 250 GV to within a 50% error. To date, there are no candidates for anti-nuclei $Z \geqslant 3$ among the approximately 250 analyzed events.

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*MSC, Houston, Texas.

PUBLICATIONS AND PAPERS

1. D. E. Greiner, P. J. Lindstrom, and H. H. Heckman, Proton Spectrum at L = 1.2 Using Solid-State Counter Telescope, Trans. Am. Geophys. Union 50, 658 (Nov. 1969).

EXPERIMENTAL PHYSICS

Edward J. Lofgren in charge

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

A. R. Clark, Bruce Cork,* T. Elioff,† L. T. Kerth, T. N. Rangaswamy,‡ and W. A. Wenzel

An optical spark chamber-counter experiment was performed at the Bevatron to study details of the π-π interaction exhibited in the reaction $\pi^- + p \rightarrow \pi^+ + \pi^- + n$ at incident pion momenta of 3, 4, 4.5, and 5 BeV/c. Our data consist of 1.6×10^5 events satisfying the above hypothesis with low 4-momentum transfer to the nucleon. This sample is the largest collected so far in a single experiment and is comparable to the compilations of all bubble-chamber data on this reaction.

In addition to the ρ meson, the dipion mass spectrum shows evidence for the decay $\omega \rightarrow \pi^+ \pi^-$ away from the minimum momentum transfer region. At our higher incident momenta there is also evidence for another enhancement at a mass ≈ 936 MeV with width $\Gamma \approx 47$ MeV. Analysis of the dipion data is continuing and the di-kaon data will be analyzed shortly.

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MEASUREMENT OF THE $(K^+ \rightarrow e^+ \nu)/(K^+ \rightarrow \mu^+ \nu)$ BRANCHING RATIO

Alan R. Clark, Bruce Cork,* Tom Elioff,† David Newton,‡ Leroy T. Kerth, John F. McReynolds, and W. A. Wenzel

The Bevatron experimental run was completed in June 1968. About one-quarter million photographs were taken, 90% of these with the analyzing magnet set for $K^+ \rightarrow e^+ \nu$. Analysis of 60% of the data has been completed, yielding 61.4 ± 11 events after a background subtraction. This is to be compared with the previous world's total of 17.0 ± 7.5. The other 40% of the data is expected to have a smaller background subtraction and hence higher accuracy. These data have been scanned and measured and are under analysis.

The presently analyzed result

$$\frac{\Gamma(K \rightarrow e\nu)}{\Gamma(K \rightarrow \mu\nu)} = 2.27 \pm 0.39 \times 10^{-5}$$

is in agreement with the V-A prediction of 2.19×10^{-5}. This prediction includes radiative corrections.

The branching fraction of $K \rightarrow e\nu\gamma$ to all K decays has also been measured for $p_e \geq 240$ MeV/c, with four events giving

$$\frac{\Gamma(K \rightarrow e\nu\gamma)}{\Gamma(K \rightarrow \text{all})} = 2 \times 10^{-6}.$$

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‡University of Lancaster, England.

MEASUREMENT OF pp AND np TRIPLE-SCATTERING PARAMETERS FROM 510 TO 670 MeV

Charles M. Ankenbrandt,* David Cheng,† Leroy T. Kerth, K. C. Leung,‡ Burns Macdonald,** and Pamela T. Surko††

Analysis of the data from this experiment is complete. The values of the Wolfenstein triple scattering parameters D, R, and R' had been determined at laboratory kinetic energies 670, 600, and 520 MeV for the p-p interaction, over the c.m. angular range 30° to 120°; and the values of the parameters D^t, R^t, and R'^t have been determined at 600 and 520 MeV for the free n-p interaction, over the c.m. angular range 65° to 180°.

A polarized neutron/proton beam was produced by elastically scattering the Berkeley 184-in. cyclotron beam off a deuterium/hydrogen target. The polarized beam was elastically scattered off a second hydrogen target, and the momentum and polarization of the recoil proton were analyzed in a carbon slab and magnetostrictive wire spark chamber spectrometer analyzer.

A publication is now in progress.

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†Brookhaven National Laboratory, New York.
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NEUTRAL LEPTONIC CURRENTS

Alan R. Clark, Tom Elioff,* R. Clive Field, Henry J. Frisch, Rolland P. Johnson, Leroy T. Kerth, and W. A. Wenzel

A double, spark-chamber spectrometer was used to search for the decays $K_L^0 \to \mu^+\mu^-$, $K_L^0 \to e^+e^-$, and $K_L^0 \to \mu e$ as evidence for neutral leptonic currents in weak interactions. As of the first of September 1970, sufficient data had been accumulated and analyzed to set new limits for $K_L^0 \to \mu\mu$, ee, or $\mu e/K_L^0 \to$ all of $< 6\times10^{-9}$ (90% C. L.). Compared with previous measurements, these limits correspond to increases in sensitivity of factors of 35, 25, and 620, respectively. Preliminary results were presented at the 1970 Kiev Conference.

The measured limit of $K_L^0 \to \mu\mu$ is as low or lower than that predicted by most theoretical calculations. Consequently, a longer run to verify these limits is now being considered. Invariant mass resolution of 1/3% should easily allow the extension of the experiment before problems with $K \to \pi\mu\nu$ background are encountered.

$K_L^0 \to \pi\mu\nu$ and $K_L^0 \to \pi e\nu$ events accumulated during the neutral-current search are now being analyzed for information on the $K_{\ell 3}$ form factors and on the mass of the muon neutrino.

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SEARCH FOR "MINIONS"

Alan R. Clark, R. Clive Field, Henry J. Frisch, Rolland P. Johnson, Leroy T. Kerth, R. C. Sah, Gilbert Shen, W. A. Wenzel, and Arthur R. Zingher

This experiment is a search for neutral particles (24 to 486 MeV/c^2) which decay into electron-positron pairs. If such neutral particles were produced by the external proton beam striking a copper target, then the electron-positron pairs arising from their decays would be detected by the double spectrometer which was constructed for the search for neutral leptonic currents.

Approximately 100 hours of data were taken at the end of July 1970. These data have been analyzed, and no mass peak indicating the existence of such neutral particles was observed. Upper limits on the differential production cross section for such particles will be presented. The data will also be analyzed to search for $e\pi$, $e\mu$, $\pi\pi$, $\pi\mu$, and $\mu\mu$ resonances.

PUBLICATIONS AND PAPERS

1. Pamela Hansen Surko, Nucleon-Nucleon Triple-Scattering Parameters 510-670 MeV (Ph.D. Thesis), UCRL-19451, January 1970.
2. Rolland P. Johnson, Weak Interactions: On the Existence of Neutral Leptonic Currents (Ph. D. Thesis), UCRL-19709, April 1970.
3. Kwok-Chu Leung, Measurement of NP (PP) Triple Scattering Parameters $R^t(R)$ and $R'^t(R')$ 510 to 670 MeV (Ph.D. Thesis), UCRL-19705, March 1970.
4. T. N. Rangaswamy, Study of Dipions in the Mass Range 400 to 1000 MeV produced in $\pi^- p$ Collisions (Ph.D. Thesis), UCRL-19464, May 1970.
5. A. R. Clark, T. Elioff, R. C. Field, H. J. Frisch, R. P. Johnson, L. T. Kerth, and W. A. Wenzel, Experimental Limit on the Branching Ratio for $K_L^0 \rightarrow \ell\ell$ (UCRL-20078, August 1970).
6. A. R. Clark, B. Cork, T. Elioff, L. T. Kerth, J. F. McReynolds, D. Newton, and W. A. Wenzel, A Measurement of the Branching Ratio $K^+ \rightarrow e^+\nu/K^+ \rightarrow \mu^+\nu$ (UCRL-20079, August 1970).

EXPERIMENTAL PHYSICS

Burton J. Moyer and A. Carl Helmholz in charge

STUDY OF THE DECAY MODES $K_L^0 \to 2\pi^0$, $K_L^0 \to 3\pi^0$

I. Linscott, W. P. Oliver, S. Parker, V. Z. Peterson,* and C. Rey

The process of refining the measurement and analysis of the spark chamber events is continuing toward the goal of enhancing the relationship of the smal $2\pi^0$ "signal" to its background, and thus reducing the systematic errors assigned to our first published value of $|\eta_{00}|^2$.

Re-scanning and selection of spark chamber pictures for $K_L^0 \to 2\pi^0$ events have been completed, removing one possible source of systematic error. A study of chamber response for 200- to 500-MeV gammas has also been completed using gammas of known energies from $\pi^- + p \to n + \eta$, $\eta \to 2\gamma$; these data being available from an experiment on η^0 decay modes done with the spark chamber array subsequent to the K_L^0 experiment. Furthermore, improved information on shower-pointing directions and their deviations from the directions of the photons producing the showers has been obtained from measurements of showers from a small aluminum target placed at the center of the decay volume in the π^- beam.

These improved calibration techniques, together with an improved method of assessing the equivalent spark count of a shower in the chambers, are expected to improve both the resolution of the experiment and the signal-to-background ratio. Final testing of the analysis programs using regenerator data is now under way; and we expect to complete, this year, a full-scale article giving final results with reduced statistical and systematic uncertainties.

The study of the momentum dependence of the matrix element for the decay $K_L^0 \to 3\pi^0$ now utilizes the SASS automatic scanning - pattern recognition system and approximately 8000 six-shower events will be obtained. Kinematic fitting procedures are being developed to optimize gamma pairing, and exhibit errors and biases.

*University of Hawaii.

STUDY OF $K^+ \to \pi^+\pi^-e^+\nu$

Brownlee Gauld, Victor Perez-Mendez, Robert Cence,* Fred Harris,* Brian Jones,* Richard Morgado,* Michael Peters,* Leroy Shiraishi,* David Yount,* Douglas Clarke,† David Cline,† and Robert Frommer†

During November and early December 1969 we took a small sample of data, from which we successfully reconstructed about 15 K_{e4} events. We also were able to successfully reconstruct τ decays, but with an efficiency of only 10%. We had reason to believe that this was due to inadequacies in the software.

Following the January-February 1970 shutdown, we began taking the bulk of our data, and between March and June recorded 1.5×10^6 triggers on tape. Concurrently and through the summer the software was improved to take account of the various imperfections in the spark chambers, including spark inefficiency

and multiple sparking.

By the end of the summer, our analysis efficiency had improved to 55 to 85%, the uncertainty being due to the fact that there is some disagreement between the two methods of calculation of the analysis efficiency. At the end of the summer the Hawaii group took the data tapes back to their University where the bulk of the analysis will be carried out on the Hawaii IBM 360-65 computer. The conversion of the various programs to the IBM computer has just been completed, opening the way to serious data analysis.

*University of Hawaii.
†University of Wisconsin.

η^0 DECAY AND $\pi^0\pi^0$n EXPERIMENTS

Roger Chaffee, Orin Dahl,* Robert W. Kenney, Jerry Nelson, Morris Pripstein,* Thomas B. Risser, Andris Skuja, and Michael A. Wahlig*

Both phases of this work are collaborations with several members of Group A. They are designed to study neutral final states consisting of γ rays and neutrons, deriving from the reactions $\pi^- p \rightarrow \eta^0 n$ (710 to 1140 MeV/c) and $\pi^- p \rightarrow \pi^0\pi^0 n$ (1.5 to 2.5 GeV/c), respectively.

The first of three separate experiments is a study of neutral final states in η decay, which hopefully will rectify the present disagreements among existing branching-ratio measurements. Final film analysis is currently under way. Preliminary results were submitted to the Lund International Conference on Elementary Particles and also appeared as the thesis of T. B. Risser.[1]

The second experiment is complete through the running stage. The reactions $\pi^+ p \rightarrow N^*_{1/2}(1680) \rightarrow \eta n$ and $\pi^- p \rightarrow N^*_{1/2}(1688) \rightarrow \eta n$ have been seen in appreciable numbers in the analysis. There exists an SU(3) prediction of 0.3 mb for an ηn final state via either D_{15} [$N^*(1680)$] or F_{15}[($N^*(1688)$] intermediate states. Neither reaction has been observed prior to our work, and our analysis is tentatively able to identify $N^*_{1/2}$ intermediate states. Clean separation of η final states has been achieved, and only a few minor problems remain in the data-analysis system. An abstract covering preliminary results was submitted to the Lund International Conference on Elementary Particles.

The third experiment in this series is a relatively comprehensive study of the $\pi^0\pi^0$ system in the reaction $\pi^- p \rightarrow \pi^0\pi^0 n$; running has also been completed on this one. A total of 75,000 four-shower and 45,000 three-shower events were collected. Their analysis is proceeding, and preliminary results will be available within a very few months. Some sketchy first results were communicated to the rapporteur at the Kiev Conference.

In each experiment, γ rays were detected by a five-side cube of lead-plate spark chambers used by the Moyer-Helmholz group for the recent $K_L^0 \rightarrow \pi^0\pi^0$ experiment at the Bevatron. Neutrons were detected by 20 large scintillation counters, and the spark-chamber system was triggered by neutrons with the desired time of flight.

The existing spark chamber array has been used without rearrangements to date, and expected performance of the apparatus has been achieved in all respects. For our third ($\pi^0\pi^0$n) experiment a new pion beam was constructed; it operated as designed over a momentum range from 1.6 GeV/c to 2.4 GeV/c.

*Group A Physics, LRL.

1. T. B. Risser, Neutral Decays of the η Meson, UCRL-20039, August 1970.

COMPARISON OF THE LIFETIMES OF POSITIVE AND NEGATIVE PIONS

David S. Ayres, David O. Caldwell,* Allan M. Cormack,† Virgil B. Elings,* Arthur J. Greenberg,‡ William P. Hesse,* Robert W. Kenney, and Rollin J. Morrison*

Our results and experimental methods have been reported in a series of papers. See last Semiannual Physics Report. The final account of this work is in press at Physical Review.[1]

*University of California, Santa Barbara.
†Tufts University.
‡Deceased, July 14, 1970.

1. D. S. Ayres, A. M. Cormack, A. J. Greenberg, D. O. Caldwell, V. B. Elings, W. P. Hesse, R. J. Morrison, Measurements of the Lifetimes of Positive and Negative Pions, Phys. Rev. (in press).

μ^--CAPTURE NUCLEAR γ RAYS[1]

S. Kaplan, R. Pyle, E. Temple, and G. Valby

This is an exploratory study of the feasibility of using muon capture to investigate nuclear structure. Data reduction and analysis of the gamma-ray spectra emitted by residual nuclei following μ^- capture in Al, Si, Ca, Co, and Ni are in progress. The weak interaction of muons with nucleons, $\mu^- + p \rightarrow n + \nu$, followed by frequent emission of a neutron suggests this process as a method for exciting simple shell-model configurations in the residual nuclei. Indeed, levels in ^{39}K [a residual from $^{40}Ca(\mu^-, \nu)\ ^{40}K^*$ with a neutron emitted from $^{40}K^*$] which correspond to the levels interpreted as single-hole levels in $^{40}Ca(t, \alpha)\ ^{39}K^*$ are observed. As with our previously reported ^{16}O results, the strong presence of the giant dipole resonance is indicated by the similarity of the spectrum and Doppler broadening to that produced by photoexcitation in the resonance region.

To aid interpretation and normalization of the prompt γ-ray spectra, a measurement was made of total transition rates to find nuclear ground states. In the method used the nuclides were identified by detecting characteristic γ rays following β decay. The cyclotron was operated in a square-wave mode with a 32-sec period, and the γ rays were detected during beam-off time. For our targets the reaction rates measurable by this technique were $^{27}Al(\mu^-, \nu)\ ^{27}Mg$, $^{27}Al(\mu^-, \nu np)\ ^{25}Na$, $^{28}Si(\mu^-, \nu)\ ^{28}Al$, $^{28}Si(\mu^-, \nu p)\ ^{27}Mg$, $^{40}Ca(\mu^-, \nu 2n)\ ^{38}K$, $^{59}Co(\mu^-, \nu np)\ ^{57}Mn$.

1. S. N. Kaplan, R. V. Pyle, L. E. Temple, and G. F. Valby; Doppler Broadening of the 6.322-MeV γ Ray from ^{15}N Following μ^- Capture in ^{16}O, in High-Energy Physics and Nuclear Structure, Samuel Devons, Ed. (Plenum Press, New York, 1970), pp. 163-165.

π^0 FORM-FACTOR EXPERIMENT

A. W. Stetz, B. M. Smith, V. Perez-Mendez, and D. Fredrickson

The experimental run to measure the form factor of the π^0 meson by studying wide-angle Dalitz decays was completed November 1969. In this experiment we used magnetostrictive spark chambers to measure the vector momentum of the electron-positron pair in the decay $\pi^0 \rightarrow e^+ + e^- + \gamma$. We obtained 10^6 triggered events; of these we expect $\sim 10^4$ to have a sufficiently large relative momentum between the two leptons so that the form factor is sensitive to their distributions. The data are currently being analyzed.

$\pi^- + {}^3He$ INTERACTIONS

J. M. Sperinde, B. M. Smith, V. Perez-Mendez, D. Fredrickson, and R. Hinkins

The experimental run in this experiment was completed February 1969. In this experiment we measured the elastic and inelastic scattering of π^- from ^3He and the double charge-exchange reaction $\pi^- + {}^3He \rightarrow 3n + \pi^+$. The data from the latter reaction have been

analyzed, and the measured momentum distribution of the π^+ mesons indicates the possible existence of a low-energy resonance among the three neutrons with a width of ~12 MeV located at a few MeV above threshold. This is consistent with a similar effect found in the three-proton case in an experiment done at the Rutherford Laboratory. The results of this experiment have been published in Physics Letters.[1]

1. J. Sperinde, D. Fredrickson, R. Hinkins, V. Perez-Mendez, B. Smith, Phys. Letters 32B, 185 (1970).

$p + d \rightleftarrows {}^3He + \gamma$: TIME-REVERSAL EXPERIMENT

D. Fredrickson, M. Goitein, V. Perez-Mendez, A. W. Stetz, C. Prescott,* C. Heusch,* R. Kline,* J. Carroll,† and B. McDonald†

This experiment consists of measuring the differential distributions in the forward and inverse reactions $p + d \rightleftarrows {}^3He + \gamma$, and comparing them at the same c. m. energies. The photodisintegration experimental run was done at Cal Tech, ending in January 1970. The $p + d \rightarrow {}^3He + \gamma$ experiment is being setup at the cyclotron. Monochromatic beams of protons at 600, 500, 400, and 300 MeV have been tested, as well as the rest of the detector apparatus: 2 wire spark chambers, lead glass Cerenkov counters for γ detection, and a large scintillator for measuring the energy of the ${}^3He$ recoils. We expect to start data taking in October 1970.

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†University of Virgina.

π^+ RADIATIVE DECAY EXPERIMENT: $\pi^+ \rightarrow e^+ + \gamma + \nu$

A. W. Stetz, K. Stein, M. Goitein, and V. Perez-Mendez

An experiment to measure the ratio of the axial-vector and vector form factors in this decay, by measuring the angular and energy distribution of the e^+ and γ, has been proposed and accepted by the cyclotron scheduling committee.

This experiment will use magnetostrictive wire chambers in a magnet to determine the momentum of the e^+ and lead glass Cerenkov counters to determine the energy of the γ. A beam layout to give a flux of stopping π^+ ~10^6/sec has been designed. This beam was designed in collaboration with the University of Arizona who will use it ahead of us. We expect to start this experiment in May 1971. Based on the kinematics that we propose, we expect to obtain ~250 decay events within the energy and momentum limits that are sensitive to the form-factor measurement.

INSTRUMENTATION

R. Grove, V. Perez-Mendez, A. Rindi, J. Sperinde, and G. Stoker

During this period, two papers on work done previously were published in the proceedings of the 1969 Dubna Conference on High Energy Instrumentation.[1, 2]

We have continued to work on the use of delay lines to read out the position of ionization events in wire proportional chambers. Starting with a ferrite-loaded delay line which gave a position accuracy of ~2 to 3 mm,[3] we have extended this effort to the use of ceramic-core lines which have less dispersion and more delay per unit length. In view of the delay line's ability to give a signal which interpolates the resultant pulse from a number of adjacent wires, we have shown recently that a readout of this type, which receives the signal from the wire planes that detect the induced charge from the motion of the positive ions, is able to achieve a position accuracy of ± 0.15 mm.[4]

We are continuing work to improve on this accuracy by use of delay lines with more

delay per unit length and by the use of better timing discriminators.

We applied one of our wire spark chambers to the problem of measuring the spatial distribution of stopping π^- beams in tissue-like material.[5] This was done by locating the distribution of γ rays of energy greater than 20 MeV emitted in the π^- capture reactions. This technique will be useful in locating the spatial distribution of the Bragg peak of π^- beams that will be used in cancer therapy at the high-current accelerators under construction at Los Alamos and other laboratories.

1. V. Perez-Mendez, On the Use of Amorphous Semi-Conductors in Particle Detectors with High Spatial Resolution over Wide Areas, in Proc. Int. Conf. on Filmless Spark and Streamer Chambers, Dubna, U.S.S.R. (Nov. 1969), p. 213.
2. V. Perez-Mendez, J. M. Sperinde, and A. W. Stetz, Wire Spark Chambers in Spectrometer Experiments (UCRL-18846, April 1969), in Proc. Int. Conf. on Filmless Spark and Streamer Chambers, Dubna, U.S.S.R. (Nov. 1969), p. 208.
3. A. Rindi, V. Perez-Mendez, R. L. Wallace, Delay-Line Readout for Proportional Chambers (UCRL-19255), Nucl. Instr. Methods 77, 325 (1970).
4. R. Grove, K. Lee, V. Perez-Mendez, and J. Sperinde, Electromagnetic Delay Line Readout for Proportional Wire Chambers (UCRL-19858, June 1970), Nucl. Instr. Methods (in press).
5. A. J. Miller, V. Perez-Mendez, M. R. Raju, A. Rindi, J. Sperinde, A Method for Mapping the Spatial Distribution of Stopping π^- Mesons in Tissue (UCRL-19376 Rev., Feb. 1970), submitted to Physics in Medicine and Biology.

OPTICAL TIMING OF THE CRAB NEBULA PULSAR NP 0532

Jerry Nelson, Richard Hills,* David Cudaback,* and Joseph Wampler†

The timing of the pulses from the Crab Nebula pulsar NP 0532 has been studied since December 1969. This is the only known optically visible pulsar; and since it is the youngest pulsar known, its study furnishes the most critical tests of theories of pulsars. The results of the first six months of our data have been published in the Astrophysical Journal,[1] and have been reported at the International Symposium on the Crab Nebula, August 5-7, 1970, Manchester, England.

*University of California, Berkeley.
†Lick Observatory, University of California, Santa Cruz.

1. J. Nelson, R. Hills, D. Cudaback, J. Wampler, Optical Timing of the Crab Nebula Pulsar NP 0532, Astrophys. J. 161, L235 (1970).

PUBLICATIONS AND PAPERS

1. S. N. Kaplan, R. V. Pyle, L. E. Temple, and G. F. Valby, Doppler Broadening of the 6.322-MeV γ Ray from ^{15}N Following μ^- Capture in ^{16}O, in High-Energy Physics and Nuclear Structure, Samuel Devons, Ed. (Plenum Press, New York, 1970), pp. 163-165.
2. J. Sperinde, D. Fredrickson, R. Hinkins, V. Perez-Mendez, B. Smith, Phys. Letters 32B, 185 (1970).
3. V. Perez-Mendez, On the Use of Amorphous Semi-Conductors in Particle Detectors with High Spatial Resolution over Wide Areas, in Proc. Int. Conf. on Filmless Spark and Streamer Chambers, Dubna, U.S.S.R. (Nov. 1969), p. 213.
4. V. Perez-Mendez, J. M. Sperinde, and A. W. Stetz, Wire Spark Chambers in Spectrometer Experiments (UCRL-18846, April 1969), in Proc. Int. Conf. on Filmless Spark and Streamer Chambers, Dubna, U.S.S.R. (Nov. 1969), p. 208.
5. A. Rindi, V. Perez-Mendez, R. L. Wallace, Delay-Line Readout for Proportional Chambers, Nucl. Instr. Methods 77, 325 (1970).
6. R. Grove, K. Lee, V. Perez-Mendez, and J. Sperinde, Electromagnetic Delay Line Readout for Proportional Wire Chambers (UCRL-19858, June 1970), Nucl. Instr. Methods (in press).

7. A. J. Miller, V. Perez-Mendez, M. R. Raju, A. Rindi, J. Sperinde, A. Method for Mapping the Spatial Distribution of Stopping π^- Mesons in Tissue (UCRL-19376 Rev., Feb. 1970), submitted to Physics in Medicine and Biology.
8. T. B. Risser, Neutral Decays of the η Meson (UCRL-20039, August 1970).
9. D. S. Ayres, A. M. Cormack, A. J. Greenberg, D. O. Caldwell, V. B. Elings, W. P. Hesse, R. J. Morrison, Measurements of the Lifetimes of Positive and Negative Pions, Phys. Rev. (in press).
10. J. Nelson, R. Hills, D. Cudaback, J. Wampler, Optical Timing of the Crab Nebula Pulsar NP 0532, Astrophys. J. 161, L235 (1970).

EXPERIMENTAL PHYSICS

Wilson M. Powell and Robert W. Birge in charge

TWO-PRONGED EVENTS FROM π^+p INTERACTIONS IN THE C.M. ENERGY RANGE 1740 to 2130 MeV

Robert W. Birge, George E. Kalmus, and William B. Michael

Three new exposures in the 25-inch bubble chamber at incident π^+ momenta of 1.15, 1.20, and 1.95 GeV/c have been made during the period of this report. This brings to twelve the number of incident momenta and to 1 400 000 the total number of pictures being analyzed in the c.m. energy range 1740 to 2130 MeV.

Determination of the π^+p elastic cross section and angular distribution has been completed at eight momenta and submitted for publication in a form suitable for use in phase-shift analyses.[1] Processing of the remaining four momenta is in progress.

Preliminary analysis of the $\pi^+p\,\pi^0$ channel has been carried out at six momenta, in collaboration with a group at U.C. Riverside. The production angular distribution for $\pi^+p \rightarrow \Delta^{++}\pi^0$ has been determined[2] and gives evidence that s-channel resonances are strongly coupled to $\Delta\pi$ in this energy region. At the same time it is observed that dips at $t = t_{max}$ and $t = \simeq -0.5\,(\mathrm{GeV/c})^2$, characteristic of ρ exchange with dominant helicity-flip coupling, are present at all momenta. These distributions have been fitted with s-channel resonances, as given by elastic partial-wave analyses, and again with s-channel resonances plus a Regge ρ amplitude. The latter fit is in better agreement with the data. This is not taken to imply that the duality picture is inadequate, but may simply indicate that some resonances are missing from the elastic phase-shift analysis solutions. Preliminary examination of the ρ^+p production angular distribution[3] indicates that this channel is not strongly coupled to the nucleon resonances. Descriptions of this process in terms of one-pion exchange with absorption and Reggeized pion exchange are being attempted.

1. G. E. Kalmus, W. Michael, R. W. Birge, S. Y. Fung, and A. Kernan, π^+p Elastic Scattering Data Between 1820 and 2090 MeV c.m. Energy (UCRL-19775, August 1970), presented at XVth Int. Conf. on High-Energy Physics, Kiev, Aug. 26- Sept. 4, 1970; Phys. Rev. (to be published).
2. R. W. Birge, G. E. Kalmus, W. Michael, U. Mehtani, S. Y. Fung, A. Kernan, Y. Williamson, $\pi^+ + p \rightarrow \Delta^{++}(1236) + \pi^0$ at 1.85 = 2.09 GeV--A Study of s- and t-Channel Effects (U. C. Riverside Report UCR-P107-108, August 1970), presented at XVth Int. Conf. on High-Energy Physics, Kiev, Aug. 26-Sept. 4, 1970.
3. R. W. Birge, G. E. Kalmus, W. Michael, Y. Williamson, S. Y. Fung, A. Kernan, U. Mehtani, R. T. Poe, T. L. Schalk, and B. C. Shen, A Study of $\pi^+p \rightarrow \rho^+p$ at 1.85 - 2.09 GeV (U. C. Riverside Report UCR-P107-110, August 1970), presented at XVth Int. Conf. on High-Energy Physics, Kiev, Aug. 26-Sept. 4, 1970.

STRANGE PARTICLE PRODUCTION FROM π^+p INTERACTIONS

George E. Kalmus, Philip Hanson, and James Louie*

Data at nine π^+ momenta in the range 1200 to 1850 MeV/c have been obtained in the following three-body final states:

$\Sigma^+K^+\pi^0$, $\Sigma^+K^0\pi^+$, $\Sigma^0K^+\pi^+$, $\Lambda K^+\pi^+$, pK^+K^0. The data consist of cross sections, Dalitz plots, and angular distributions for the quasi-two-body final state $Y^{*+}(1385)K^+$. In the channel $Y^{*+}(1385)K^+$ the production and Y^* decay distributions have been compared with the predictions of simple resonant s-channel and K^* exchange t-channel models. A paper presenting the data has been submitted for publication.[1] Processing of data on strange-particle production in π^+p interactions in the c.m. energy range 2130 to 2440 MeV is currently in progress.

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*Brookhaven National Laboratory, Upton, Long Island, New York.

1. P. Hanson, G. E. Kalmus, and J. Louie, Strange-Particle Production From π^+p Interactions in the c.m. Energy Range 1820 - 2090 MeV presented at XVth Int. Conf. on High-Energy Physics, Kiev, Aug. 26-Sept. 4, 1970; submitted to Phys. Rev.

NEW DATA IN THE REACTION $\pi^+p \to \Sigma^+K^+$ AT 1.28 AND 1.41 GeV/c AND A TEST OF CHARGE INDEPENDENCE IN THE c.m. ENERGY RANGE 1.820 TO 2.090 GeV

George E. Kalmus, Giovanni Borreani* and James Louie†

Data at two incident π^+ momenta (1.28 and 1.41 GeV/c) in the reaction $\pi^+p \to \Sigma^+K^+$ have been submitted for publication.[1] Our previous partial-wave analysis of this reaction is extended to include these data. Charge independence is tested over the c.m. energy range 1.820 to 2.090 GeV; we used our data for the Σ^+K^+ channel and published data for the $\pi^-p \to \Sigma^0K^0$ and Σ^-K^+ channels.

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†Brookhaven National Laboratory, Upton, Long Island, New York.

1. G. E. Kalmus, G. Borreani, and J. Louie, New Data in the Reaction $\pi^+p \to \Sigma^+K^+$ at 1.28 and 1.41 GeV/c and a Test of Charge Independence in the c.m. Energy Range 1.820 to 2.090 GeV (UCRL-19777, August 1970), presented at XVth Int. Conf. on High-Energy Physics, Kiev, Aug. 26-Sept. 4, 1970; submitted to Phys. Rev.

STUDY OF THE REACTION $\pi^+p \to \Sigma^+K^+$ BETWEEN 1850 AND 2090 MeV c.m. ENERGY

George E. Kalmus, Giovanni Borreani,* and James Louie†

Angular distributions and polarization measurements (obtained from bubble chamber data) have been obtained at seven incident π^+ momenta in the reaction $\pi^+p \to \Sigma^+K^+$. A paper has been submitted for publication.[1] Results of a partial-wave analysis as well as an s-, t-, and u-channel analysis are presented. The branching fraction of the $\Delta(1950) \to \Sigma^+K^+$ was found to be $2.0 \pm 0.4\%$.

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†Brookhaven National Laboratory, Upton, Long Island, New York.

1. G. E. Kalmus, G. Borreani, J. Louie, Study of the Reaction $\pi^+p \to \Sigma^+K^+$ Between 1850 and 2090 MeV c.m. Energy (UCRL-19735, March 1970), submitted to Phys. Rev.

THE REACTION $\pi^+p \to \omega^0\Delta^{++}$ AT 2.3 AND 2.67 GeV/c

Winston Ko, George Gidal, and Donald F. Grether

We have made an analysis of the quasi-two-body final states $\omega^0\Delta^{++}(1238)$ and $\rho^0\Delta^{++}$.[1] The data are from an exposure of the LRL 25-inch hydrogen bubble chamber to π^+ mesons at 2.3 and 2.67 GeV/c. For $\omega^0\Delta^{++}$ we have some 1500 events at 2.3 GeV/c and 3000 events at 2.67 GeV/c; for $\rho^0\Delta^{++}$ some 2000 and 3000 events, respectively. A study of ρ-ω interference and its relationship to production mechanisms is discussed.

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1. W. Ko, G. Gidal, and D. F. Grether, The Reaction $\pi^+p \to \omega^0\Delta^{++}$ at 2.3 and 2.67 GeV/c (UCRL-19779, August 1970), presented at XVth Int. Conf. on High-Energy Physics, Kiev, Aug. 26-Sept. 4, 1970.

THE REACTION $\pi^+p \rightarrow \eta^0\Delta^{++}$ BETWEEN 1.3 AND 4 GeV/c; A MEASUREMENT OF THE EFFECTIVE A_2 TRAJECTORY

Donald F. Grether, G. Borreani,* and George Gidal

Results have been obtained[1] on the reaction $\pi^+p \rightarrow \eta^0\Delta^{++}(1238)$ based on some 2000 events identified from film taken in the LRL 25-in. and 72-in. bubble chambers. The events are in the momentum range 1.3 to 4 GeV/c. Thus the data begin near threshold, span the region of the $\Delta^{++}(1950)$, and extend into the intermediate- to high-energy region. We have shown that a Regge model for A_2 exchange gives a generally adequate description of the shape of the differential cross section and of the Δ^{++} decay intensity matrix elements over the entire range of momenta.

*Istituto di Fisica dell'Universita, Torino, Italy.

1. D. F. Grether, G. Borreani, and G. Gidal, The Reaction $\pi^+p \rightarrow \eta^0\Delta^{++}$ Between 1.3 and 4 GeV/c; A Measurement of the Effective A_2 Trajectory (UCRL-19778, August 1970), presented at XVth Int. Conf. on High-Energy Physics, Kiev, Aug. 26-Sept. 4, 1970.

K^-p EXPOSURES

Robert W. Birge, Robert P. Ely, Jr., Dan Kane, and Andrew Van Horn

Data reduction has been completed for the three topologies: events with vees, events with kinks, and three-prong (τ) decays. Roughly 10% of the vee topology has been check scanned; a second scan was made of about 60% of the other two. Kinked events found only on the second scan were measured. Scanning and measuring were done on the COBWEB system.

Geometrical reconstruction, kinematic fitting, and event selection used the FOG-CLOUDY-FAIR system of the Data Handling Group. The kinematic fitting program had been recently improved for kinked event topologies; therefore, kinked events from an old exposure have been refit and treated along with the recent exposure (altogether 20 600 good Σ^- events, 23 600 good Σ^+ events). Ionization scans have been completed for both kinked events and vees to resolve ambiguities.

Data analysis is proceeding. We are determining scanning efficiencies and throughput efficiencies for the systems. The information from the τ decays establishes the path length for beam tracks at each energy. We have obtained preliminary cross sections for the following channels: $\Lambda\pi^0$, $\Sigma^\pm\pi^\mp$, and $\Sigma^\pm\pi^\mp\pi^0$. These along with preliminary partial-wave analyses were presented to the XVth International Conference on High-Energy Physics, Kiev.[1,2]

The partial-wave analysis in the $\Lambda\pi$ channel covered energies from 1865 MeV to 2001 MeV and showed that the data were compatible with an F15 resonance at 1911 MeV with a full width of 74 MeV, amplitude of resonance of 0.085, and in phase with the coupling of the $\Sigma(1775)$ resonance.

The partial-wave analysis in the $\Sigma\pi$ channel concentrated on the energy range 1733 to 1865 MeV, obtaining resonant parametrization in the D05 and F05 amplitudes in general agreement with previous studies. A single fit over the energy region 1844 to 2001 MeV showed that the data were compatible with resonant structure in F15 (with mass of 1915 MeV) and in F17 (with mass of 2030 MeV). If the F15 is purely resonant, the fit gives an amplitude at resonance of 0.14 with resonant phase the same as both the D05 and F05.

1. R. P. Ely, Jr., R. W. Birge, J. Hoven, G. E. Kalmus, D. Kane, and A. Van Horn, Study of the $\Sigma(1915)$ Resonance in the Reaction $K^-p \rightarrow \Lambda\pi^0$ (UCRL-19789, August 1970), presented at XVth Int. Conf. on High-Energy Physics, Kiev, August. 26-Sept. 4, 1970.

2. D. Kane, R. W. Birge, R. P. Ely, Jr., J. Hoven, G. E. Kalmus, and A. Van Horn. $K^- p \rightarrow \Sigma^{\pm}\pi^{\mp}$ Between 1730 and 2150 MeV (UCRL-19790, August 1970), presented at XVth Int. Conf. on High-Energy Physics, Kiev, Aug. 26- Sept. 4, 1970.

K^--NEUTRON ELASTIC SCATTERING FROM $K^- d \rightarrow K^- d$ AND $K^- d \rightarrow K^- pn$ AT 1 BeV/c

Nathan N. S. Jew

Angular distributions[1] have been obtained for the reactions Kd → Kd and Kd → Kpn at incident K^- momenta of 810, 910, 1010, and 1110 MeV/c. Data have also been obtained on $K^- n$ elastic scattering assuming the impulse approximation is valid. A paper has been accepted for publication in Nuclear Physics B.[2]

1. Nathan N. S. Jew, K^--Neutron Elastic Scattering From $K^- d \rightarrow K^- d$ and $K^- d \rightarrow K^- pn$ at 1 BeV/c (Ph.D. thesis), UCRL-19359, October 1969, and UCRL-19359 Addendum, April 1970.
2. N. N. Jew and G. E. Kalmus, K^--d Elastic Scattering and $K^- d \rightarrow K^- pn$ Between 810 and 1110 MeV/c (UCRL-19491, February 1970), submitted to Nucl. Phys. B.

CLOUD-CHAMBER SEARCH FOR QUARKS

Wilson M. Powell

With twelve cloud-chambers at Livermore, counter controlled for cosmic-ray showers near 10^{15} eV, we have catalogued 16 000 tracks.[1] Droplet count in stereomicroscopes has been done on 1200 tracks at Berkeley. Automatic droplet count has been done on 4000 tracks.

Berkeley is doing the skeletonizing of tracks on FSD tables and has done about 10 000 tracks. No good candidates for quarks have been found thus far. McCusker's data would indicate that we should have found two by now.

Efforts are under way to find the one-third-charge quarks. Use of reversal film and plenty of illumination should make this possible.

1. A. F. Clark, H. F. Finn, N. E. Hansen, W. M. Powell, and D. E. Smith, The Nine-Month Progress Report on the Cloud-Chamber Quark Hunt, LRL-Livermore Report UOPE-70-18, August 1970.

DATA REDUCTION

Robert W. Birge and P. Wes Weber

With an average of 17.0 (full-time equivalent) visual measurement personnel, the following data reduction was accomplished in the past 8 months.

SCANNING

(all results from 25-in. hydrogen bubble chamber)

Experiment	Beam	Number of frames: COBWEB System	Number of frames: FSD System
45-47, 58	1.25- to 1.85-GeV/c π^+	229 276	37 568
50-52	1.1- to 1.6-GeV/c K^-	932 908	-----
53-55, 59	2.3- to 2.7-GeV/c π^+	9 616	246 456
	Subtotal	1 171 800	284 024
		Total	1 455 824

MEASURING

	Measuring hours	Number of events	Events per measuring hour
COBWEB System	2 976	66 839	22.4
FSD System			
(Two SP5B-type image plane digitizers)			
HAZE Mode	1 467	45 851	31.3
DAPR Mode	216	26 528	122.8
	4 660	139 218	

PUBLICATIONS AND PAPERS

1. Nathan N. Jew and George E. Kalmus, K^--d Elastic Scattering and $K^-d \rightarrow K^-pn$ Between 810 and 1110 MeV/c (UCRL-19491, February 1970), Nucl. Phys. B (to be published).

2. George E. Kalmus, Giovanni Borreani, and James Louie, Study of the Reaction $\pi^+p \rightarrow \Sigma^+K^+$ Between 1850 and 2090 MeV c.m. Energy (UCRL-19735, March 1970), submitted to Phys. Rev.

3. George E. Kalmus, William Michael, Robert W. Birge, Sun-Yiu Fung, and Anne Kernan, π^+p Elastic Scattering Data Between 1820 and 2090 MeV c.m. Energy (UCRL-19775, July 1970), presented at XVth Int. Conf. on High-Energy Physics, Kiev, Aug. 26-Sept. 4 1970; submitted to Phys. Rev.

4. Philip Hanson, George E. Kalmus, and James Louie, Strange Particle Production From π^+p Interactions in the c.m. Energy Range 1820 to 2090 MeV (UCRL-19776, July 1970), presented at XVth Int. Conf. on

High-Energy Physics, Kiev, Aug. 26-Sept. 4, 1970, submitted to Phys. Rev.

5. George E. Kalmus, Giovanni Borreani, and James Louie, New Data in the Reaction $\pi^+ p \rightarrow \Sigma^+ K^+$ at 1.28 and 1.41 GeV/c and a Test of Charge Independence in the c.m. Energy Range 1.820 to 2.090 GeV (UCRL-19777, July 1970), presented at XVth Int. Conf. on High-Energy Physics, Kiev, Aug. 26-Sept. 4, 1970; submitted to Phys. Rev.

6. Donald F. Grether, Giovanni Borreani, and George Gidal, The Reaction $\pi^+ p \rightarrow \eta^0 \Delta^{++}$ Between 1.3 and 4 GeV/c; A Measurement of the Effective A_2 Trajectory (UCRL-19778, August 1970), presented at XVth Int. Conf. on High-Energy Physics, Kiev, Aug. 26-Sept. 4, 1970.

7. Winston Ko, George Gidal, and Donald F. Grether, The Reaction $\pi^+ p \rightarrow \omega^0 \Delta^{++}$ at 2.3 and 2.67 GeV/c (UCRL-19779, August 1970), presented at XVth Int. Conf. on High-Energy Physics, Kiev, Aug. 26-Sept. 4, 1970.

8. Robert P. Ely, Jr., Robert W. Birge, John Hoven, George E. Kalmus, Dan Kane, and Andrew Van Horn, Study of the $\Sigma(1915)$ Resonance in the Reaction $K^- p \rightarrow \Lambda \pi^0$ (UCRL-19789, August 1970), presented at XVth Int. Conf. on High-Energy Physics, Kiev, Aug. 26-Sept. 4, 1970.

9. Dan Kane, Robert W. Birge, Robert P. Ely, Jr., John Hoven, George E. Kalmus, and Andrew Van Horn, $K^- p \rightarrow \Sigma^\pm \pi^\mp$ Between 1730 and 2150 MeV (UCRL-19790, August 1970), presented at XVth Int. Conf. on High-Energy Physics, Kiev, Aug. 26-Sept. 4, 1970.

10. Robert W. Birge, George E. Kalmus, William B. Michael, Y. Williamson, Sun-Yiu Fung, Anne Kernan, U. Mehtani, Robert T. Poe, T. L. Schalk, and B. C. Shen, A Study of $\pi^+ p \rightarrow \rho^+ p$ at 1.85 - 2.09 GeV (University of California-Riverside Report UCR-P107-110), presented at XVth Int. Conf. on High-Energy Physics, Kiev, Aug. 26-Sept. 4, 1970

11. Robert W. Birge, George E. Kalmus, William B. Michael, U. Mehtani, Sun-Yiu Fung, Anne Kernan, and Y. Williamson, $\pi^+ + p \rightarrow \Delta^{++}(1236) + \pi^0$ at 1.85 - 2.09 GeV--A Study of s- and t-Channel Effects (University of California-Riverside Report UCR-P107-108), presented at XVth Int. Conf. on High-Energy Physics, Kiev, Aug. 26-Sept. 4, 1970.

EXPERIMENTAL PHYSICS

Emilio Segrè and Owen Chamberlain in charge

LOW-ENERGY π^-p INTERACTIONS

W. Chinowsky and C. Lima

Measurement of the 590-MeV/c π^-p interactions in the Saclay 80-cm bubble chamber have been completed. Of a total of 19 000 events, 70% of which are elastic scatters, 25% are $\pi^-\pi^+n$, and 5% are $\pi^-\pi^0p$. Analysis of the inelastic events, using an angular-momentum decomposition of the amplitude for production via intermediate states containing π-n and π-π isobars, is in progress.

PROTON-DEUTERIUM INTERACTIONS IN THE INTERMEDIATE ENERGY RANGE

Eugene Colton and W. Chinowsky

We are measuring and analyzing p-d film at 6 and 8 GeV/c. The topologies of interest include 3, 4, 5, and 6 prongs. The project is intended as a companion to earlier studies of the pp interaction at 6 GeV/c. In particular we hope to study the dependence on momentum transfer of resonance production observed in selected final states. We intend to isolate reactions of the type $pn(p_s) \rightarrow (p_s)NN + X\pi$ (by means of the impulse approximation), where N represents a nucleon and X is an integer that indicates the number of π mesons produced, and p_s indicates the "spectator" proton.

A pilot analysis of approximately 12 000 events has been undertaken to obtain reaction cross sections and to develop the most effective means of hypothesis separation. The techniques developed in this analysis will be further utilized in later analyses of larger samples of data.

A paper reporting on an analysis of the reaction $pn \rightarrow pp\pi^-$ has been completed and submitted for publication to Physical Review Letters. It is UCRL-20106 and is entitled "The Reaction $pn \rightarrow pp\pi^-$ and $N^*(1470)$ Production at 6 GeV/c."

ANALYSIS OF $\pi\pi$ and $K\pi$ SCATTERING

Eugene Colton

Reactions of the type $\pi^-p \rightarrow \pi^-\pi^+n$, $\pi^-p \rightarrow \pi^-\pi^-\pi^+p$, $\pi^+p \rightarrow \pi^+\pi^-\pi^+p$, $K^+p \rightarrow K^+\pi^-\pi^+p$, $K^+p \rightarrow K^+\pi^-\pi^+p$, $K^+p \rightarrow K^0\pi^0\pi^+p$, and $K^-p \rightarrow K^-\pi^-\pi^+p$ are being analyzed in cooperation with people in other laboratories in order to obtain $\pi\pi$ and $K\pi$ scattering cross sections by means of modified Chew-Low extrapolations. Papers to be submitted for publication in the remaining part of 1970 are: (a) E. Colton et al., "Measurement of T = 2 Elastic $\pi\pi$ Cross Sections," UCRL-20053 (submitted to the XV International Conference on High Energy Physics, August 26 - September 4, 1970, Kiev, USSR). (b) E. Colton et al., "Pole Extrapolation of the Reactions $\pi^-p \rightarrow \pi^-\pi^+n$ and $\pi^+p \rightarrow \pi^+\pi^+\Delta^{++}$ (1238)," UCRL-20111. (c) A. R. Kirschbaum et al., "Measurement of T = 3/2 $K\pi$ Elastic Scattering Cross Sections from Threshold to 1.04 GeV," UCRL-19426 Rev. (d) E. Colton et al., "Analysis of $K\pi$ Scattering." This is an analysis by the International K^+ Collaboration.

ANALYSIS OF PROTON-PROTON INTERACTIONS AT 6.6 GeV/c

E. Colton, P. Schlein,* Z. Ming Ma,† and G. A. Smith†

We are completing analysis of the reactions $pp \rightarrow pp\pi^+\pi^-$ and $pp \rightarrow p\pi^+n$. Papers submitted for publication in the very near future are: (a) E. Colton et al., "The Reaction $pp \rightarrow pp\pi^+\pi^-$ at 6.6 GeV/c," UCLA-1036.[1] (b) Z. Ming Ma and E. Colton, "Evidence for a Narrow $N^{*+}(1470)$."[2] This is a Michigan State University preprint. (c) E. Colton et al., "Analysis of Two-Prong Interactions in pp Collisions at 6.6 GeV/c" (tentative title), UCRL-20216.

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1. To be published in Phys. Rev. issue D1-1.
2. Submitted for publication to Phys. Rev. Letters (Nov. 1970).

ANALYSIS OF $pp \rightarrow pp\pi^+\pi^-$

E. Colton and W. Chinowsky

We are analyzing, along with about 20 other people, the reaction $pp \rightarrow pp\pi^+\pi^-$ from 4 to 25 GeV/c. This is a collaboration involving the use of the world's data on this reaction and involves (presently) some 33 000 events. We hope to learn about the s and t dependence of processes such as $pp \rightarrow \Delta^{++}(1238)p\pi^-$, $pp \rightarrow N^*(1400)p$, and $pp \rightarrow N^*(1700)p$. Other groups are studying the data by means of multiperipheral exchange models.

QUEST FOR T VIOLATION IN ELECTROMAGNETIC INTERACTIONS OF HADRONS

Stephen Rock,* Michel Borghini,† Owen Chamberlain, Raymond Z. Fuzesy,** Charles C. Morehouse,‡ Thomas Powell, Gilbert Shapiro, Howard Weisberg,†† Robert L. Cottrell,‡‡ John Litt,† Luke Mo,*** and Richard Taylor‡‡

Our data are consistent with no T violation to a level of a ±3% change in cross section on pure hydrogen because of a change of 100% to 0% in target polarization (known as the asymmetry parameter) at each of several N^* resonances and at each q .

The results have been published in Physical Review Letters and are available as UCRL-19706.

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SEARCH FOR POLARIZATION IN ELASTIC ep SCATTERING

T. Powell,* M. Borghini,† O. Chamberlain, R. Z. Fuzesy, C. Morehouse,‡ S. Rock,** G. Shapiro, H. Weisberg,†† R. Cottrell,‡‡ J. Litt,† L. Mo,*** and R. Taylor‡‡

In an effort to find contributions of two-photon exchange to the electromagnet inter-

actions between electrons and protons, we have measured the polarization in elastic electron-proton scattering at SLAC with a polarized butanol target. Although the quantity that we measure is the dependence of differential cross section on target proton polarization, we use the usual argument to equate this to the polarization in elastic e-p scattering. This polarization is proportional to the imaginary part of the two-photon exchange amplitude. Whether T invariance is violated or not, such polarization is zero if only one-photon is exchanged, but interference between one-photon and two-photon amplitudes could give rise to some polarization.

We performed this experiment simultaneously with the search for T violation in inelastic electron scattering. We measured the scattered electron with a ten-counter missing-mass hodoscope in the SLAC 20-GeV/c spectrometer. Typically the polarization of the hydrogen in the butanol target was 35%, but fell gradually to 17% as the incident electron beam radiation damaged the target. We find 25% of our counts are due to hydrogen, the remainder coming from heavy elements in the target. We give below results reduced to pure hydrogen (100% polarized).

E_0(GeV)	q^2(GeV/c)^2	Polarization
15	0.38	-0.004±0.014
18	0.59	-0.005±0.009
18	0.98	-0.003±0.018

The results are being published and can be seen in the report UCRL-19707.

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A MEASUREMENT OF THE ASYMMETRY IN PHOTOPRODUCTION OF π^+ MESONS FROM POLARIZED PROTONS

C. Morehouse,* M. Borghini,† A. Boyarski,‡ O. Chamberlain, R. Diebold,** S. Ecklund,‡ R. Fuzesy, W. Gorn, Y. Murata,†† T. Powell,‡‡ B. Richter,‡ P. Robrish, S. Rock,*** R. Siemann,** S. Shannon, G. Shapiro, and H. Weisberg†††

We have measured the asymmetry in the cross section for the reaction $\gamma p \rightarrow \pi^+ n$ between the two states of polarization of the initial proton normal to the plane of scattering. The beam used for the photoproduction was the bremsstrahlung beam previously used by Boyarski et al. in measuring the π photoproduction differential cross sections. The final-state π was detected in the single-arm 20-GeV spectrometer. The target performed well with an average polarization of ~ 20%.

We ran at five values of momentum transfer, t, for laboratory beam energy of 16 GeV, and six values of t for beam energy of 5 GeV. The range of -t was 0.02 to 0.60 (GeV/c)^2 at 16 GeV, and 0.02 to 1.02 (GeV/c)^2 at 5 Gev. In the 21-day counting period we measured about 4 000 000 events. Of these about 25% are identified pions fitting the kinematics for single-pion production from free protons by photons at the bremsstrahlung end point. Of these only about 25% were produced from free, and polarizable protons.

The data show a sizable asymmetry at both 5 and 16 GeV. The 16-GeV data peak at -t ≈ 0.30 (GeV/c)^2 with an asymmetry of

-0.70, and the 5-GeV data peak at $-t \approx 0.80$ with an asymmetry of also about -0.70.

The results have been published in Phys. Rev. Letters 25, 835 (1970). In addition to the $\gamma p \rightarrow \pi^+ n$ reaction, we have some data for the $\gamma p \rightarrow \pi^+ \Delta^0$ reaction, $\gamma p \rightarrow \pi^- \Delta^{++}$ reaction, and $\gamma p \rightarrow K^+ \Sigma^0$, $K^+ \Lambda$ reactions. However, the statistical quality of these measurements is low.

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DEVELOPMENT OF WIRE PROPORTIONAL CHAMBERS

Ray Fuzesy, Bill Jackson, John Jaros, Fred Kirsten, Geoffrey O'Keefe, Leonard Proehl, and Herbert Steiner

Under the direction of Herbert Steiner, several of the Chamberlain group members have worked on the construction, design, and development of multiwire proportional chambers. Ray Fuzesy has developed construction techniques and successfully built 8- × 8-in. chambers with wire spacings of 1 and 2 mm; he has also assembled a gas supply system which can provide various gas mixtures to the chambers. Herbert Steiner, in addition to organizing the efforts of others, has worked with Bill Jackson, Fred Kirsten, and Leonard Proehl in developing the electronics and logic needed to read out the 196 wires of the 1-mm chambers. Two graduate students have worked with Herb Steiner to modify the prototype electronics (Geoffrey O'Keefe) and to test the chamber performance (John Jaros). Since June 1970 the electronics has been sufficiently developed to do on-line beam studies at the Bevatron beam (histograms showing numbers of events vs x and y have been presented via computer). Further work will center on the design of better chambers (new wire sizes, gas mixes, and dimensions) and the further development, construction, and testing of the chamber electronics.

SUPERCONDUCTING MAGNET FOR POLARIZED TARGET

Owen Chamberlain, James Papp, Gilbert Shapiro, and Herbert Steiner

Investigations have begun into the possibility of constructing a superconducting magnet for use with the polarized target. The advantages of such a magnet would be: (a) The possibility of operating the target at 50 kG, where, it is reported, high (~ 80%) polarization can be achieved in compounds such as ethylene glycol at temperature of 1.1°K. (b) The more open geometry resulting from an air core magnet would permit, even at 25 kG, experiments in which the target polarization direction lies in (rather than perpendicular to) the plane of elastic scattering. Such measurements are very important in determining the relative phases of spin-flip and non-spin-flip scattering amplitudes.

HELIUM-THREE COOLED CRYOSTAT FOR POLARIZED TARGET

Owen Chamberlain, Raymond Z. Fuzesy, William Gorn, Peter Robrish, Gilbert Shapiro, and Herbert Steiner

A new cryostat is being designed for polarized target operation. Cooled by pumping

on liquid helium three, it should achieve temperatures as low as 0.5°K. Experiments at other laboratories have shown that at such a temperature, high polarizations (~70%) can be achieved in such hydrogen-rich compounds as butanol and ethylene glycol.

Meanwhile research aimed at finding the optimum chemical composition for such targets continues.

KAONIC ATOM x RAYS

Clyde E. Wiegand, Donald G. Branshaft, and Raymond Kunselman*

The experiment on x rays produced by negative kaons stopped in various elements is in operation at the Bevatron. The intensities of the x-ray lines from pure isotopes of several elements are being studied.

Σ^--hyperonic atom x rays are evident in the spectrum of Cl.

*Dept. of Physics, University of Wyoming, Laramie, Wyoming.

SEARCH FOR $K^+ \rightarrow \mu^+ + \nu + \bar{\nu} + \nu$

Roger H. Hildebrand* and Rae F. Stiening

A counter experiment to search for the rare and possibly forbidden decay $K^+ \rightarrow \mu^+ + \nu + \bar{\nu} + \nu$ is being prepared for running at the Bevatron next May. The major component of the experimental apparatus is a large block of lead glass which is now on order, with delivery expected next April. Other components of the apparatus are being designed and fabricated at the present time. We hope to be able to set an upper limit of 2×10^{-6} on the branching ratio of this decay mode if it does not occur. A result of this sort would set a limit on the possible non-weak interactions of neutrinos as well as eliminate the last remaining possibility for weak neutral currents of appreciable strength.

*Dept. of Physics, University of Chicago, Chicago, Illinois.

PUBLICATIONS AND PAPERS

1. Peter R. Robrish, Owen Chamberlain, Richard D. Field, Jr., Raymond Z. Fuzesy, W. Gorn, Charles C. Morehouse, Thomas Powell, Stephen Rock, Stephen Shannon, Gilbert Shapiro, Howard Weisberg, and Michael J. Longo, Backward np Scattering with a Polarized Target (UCRL-19365), Phys. Letters 31B, 617 (1970).

2. Stephen Rock, Michel Borghini, Owen Chamberlain, Raymond Z. Fuzesy, Charles C. Morehouse, Thomas Powell, Gilbert Shapiro, Howard Weisberg, Roger L. A. Cottrell, John Litt, Luke W. Mo, and Richard E. Taylor, Search for T-Violation in the Inelastic Scattering of Electrons from a Polarized Proton Target (UCRL-19706), Phys. Rev. Letters 24, 748 (1970).

3. Thomas Powell, Michel Borghini, Owen Chamberlain, Raymond Z. Fuzesy, Charles C. Morehouse, Stephen Rock, Gilbert Shapiro, Howard Weisberg, Roger L. A. Cottrell, John Litt, Luke W. Mo, and Richard E. Taylor, Measurement of the Polarization in Elastic Electron-Proton Scattering (UCRL-19707), Phys. Rev. Letters 24, 753 (1970).

4. Michel Borghini, Owen Chamberlain, Raymond Z. Fuzesy, William Gorn, Charles C. Morehouse, Thomas Powell, Peter Robrish, Stephen Rock, Stephen Shannon, Gilbert Shapiro, and Howard Weisberg, Polarized Proton Target for Use in Intense Electron and Photon Beams (UCRL-19724), Nucl. Instr. Methods 84, 168 (1970).

5. D. H. Saxon and J. H. Mulvey, $\pi^- p$ Reactions at 456, 505, and 552 MeV/c (Oxford University), March 1970.
6. Eugene Colton and Eugene Gellert, ω Production in $pp \rightarrow pp\pi^+\pi^-\pi^0$ at 6.6 GeV/c (UCRL-19330), Phys. Rev. D1, 1979 (1970).
7. J. H. Klems, R. H. Hildebrand, R. Stiening, Limit on the $K^+ \rightarrow \pi^+ + \nu + \bar{\nu}$ Decay Rate (UCRL-19469), Phys. Rev. Letters 24, 1086 (1970).
8. G. Charpak, D. Rahm, and H. Steiner, Some Developments in the Operation of Multiwire Proportional Chambers (CERN Report) Nucl. Instr. Methods 80, 13 (1970).
9. C. C. Morehouse, M. Borghini, O. Chamberlain, R. Z. Fuzesy, W. Gorn, T. Powell, P. Robrish, S. Rock, S. Shannon, G. Shapiro, H. Weisberg, A. Boyarski, S. Ecklund, Y. Murata, B. Richter, R. Siemann, and R. Diebold, Asymmetry in π^+ Photoproproduction from a Polarized Target at 5 and 16 GeV (UCRL-19492), Phys. Rev. Letters 25, 835 (1970).
10. Eugene Colton, Peter E. Schlein, Z. Ming Ma, and Gerald A. Smith, Experimental Comparison Between On- and Off-Mass-Shell Inelasticities in $\pi^- p$ Scattering. II (UCRL-19771), to be published in Phys. Rev. (Nov. 1970).
11. S. Klein, W. Chinowsky, R. R. Kinsey, M. Mandelkern, and J. Schultz, Phys. Rev. D1, 3019 (1970).
12. J. H. Klems, R. H. Hildebrand, and R. Stiening, A Limit on the $K^+ \rightarrow \pi^+ + \gamma + \gamma$ Decay Rate, The University of Chicago Report, June 1970.

ATOMIC BEAM GROUP

Howard A. Shugart in charge

STUDIES IN LOW-ENERGY NUCLEAR PHYSICS AND IN ATOMIC PHYSICS

Members of the atomic beam group perform research directed toward testing some of the fundamental concepts of physics and toward measuring some of the electromagnetic and mechanical properties of atoms, molecules, and nuclei. Our work is characterized primarily by the use of simple atomic systems for these investigations. The methods of atomic and molecular beams, optical and electron pumping, and detection of nuclear decay constitute techniques employed in our research. These methods are noted for their sensitivity and reliability of results.

Owing to the decline in funds available to support our people and their work, a number of projects are being phased out. The status of various projects is contained in the following list.

1) Time-Reversal Invariance in the β Decay of ^{19}Ne (Girvin, Calaprice, and Commins). This experiment is now running at the 88-in. cyclotron and will be completed by the end of the summer.

2) Effect of Weak Interaction on the Strong Interaction (Simmons and Commins). It has recently been shown that this experiment is not feasible with presently accessible techniques, and therefore the work is being terminated.

3) Isotope Shifts and Atomic Stark Effect in Stable and Radioactive Atoms (Yellin and Marrus). Dr. Yellin will be leaving for a year in Israel. During his absence this project will not be pursued.

4) Lifetime of Metastable Electronic States (Van Dyck, Johnson, and Shugart). Robert Van Dyck has completed his Ph.D. thesis research on the lifetime of the 2 $^1S_0$ metastable state in helium. Dr. Johnson is presently utilizing the equipment to investigate lifetimes in the hydrogen and deuterium metastable molecule.

5) Lamb Shift by Quantum Beats and Related Phenomena (Hadeishi). Dr. Hadeishi is currently studying the phenomena of alignment in atoms induced by bombardment by heavy (50-100 keV) ions from the isotope separator.

6) Book on the Physics of Aligned Atoms (Hadeishi). This project is just starting.

7) Book on Weak Interactions (Commins). This project is now nearing completion.

8) Coherence Effects in He (Geneux). Professor Geneux has returned to Geneva and will continue these studies there.

9) Development of an Optical Pumping Magnetometer (Hadeishi). These efforts have produced a very sensitive device for detecting small changes in the ambient magnetic field for use as a ferrous metal detector. An original magnetometer employing mercury has been replaced by one using ^{133}Cs.

10) Search for a Possible Electron Mass Shift (Mowat, Johnson, and Shugart). This project has been completed and submitted for publication.

11) Spins and Moments of Radioactive Germanium Isotopes (Oluwole and Schmelling). This research is completed and published.

12) Fine Structure of Helium—Hyperfine Structure of ^{3}He (Johnson). This work has been slowed by the long delivery time of some ultraviolet interference filters. It will be resumed soon.

13) Spectrum of a Free Radical of Interest to Radioastronomers (Zak, Schmelling, and Shugart). This work encounters sizable difficulties, which are slowly being understood and overcome.

14) Computations in Nuclear Structure (Bonney). This is a continuing project.

15) Lifetimes in the decay of Hydrogen-Like and Helium-Like Atoms of High Z (Schmieder and Marrus). Many interesting measurements and effects have resulted from this work and are in the publication phase now.

16) Polarization Correlation of Successive Photons in Atomic Decays (Friedman, Clauser, and Commins). Data from this experiment are now being collected.

The activity of the group during the past six months is indicated by the following enumeration of papers published and reports issued.

PUBLICATIONS AND PAPERS

Abstracts

1. Frank P. Calaprice, Determination of the Vector Coupling Constant from the Beta Decay of Mirror Nuclei (UCRL-19353), Bull. Am. Phys. Soc. 14, 1217 (1969).
2. Stephen G. Schmelling, Vernon J. Ehlers, and Howard A. Shugart, Hyperfine Structure and Nuclear Magnetic Moment of ^{196}Au (UCRL-19394), Bull. Am. Phys. Soc. 15, 46 (1970).
3. Richard Marrus and Robert W. Schmieder, Observation of the Two-Photon Decay of the $2\,^3S_{1/2}$ States of Hydrogen-Like Si XIV, S XVI, and Ar SVIII (UCRL-19748), Bull. Am. Phys. Soc. 15, 794 (1970).
4. Tetsuo Hadeishi, Resonance Effects of Fast-Moving Excited Atoms by Spatially Periodic Potentials (UCRL-19811), submitted to Second International Conference on Beam-Foil Spectroscopy, Lysekil, Sweden, June 7-12, 1970.

Papers

1. Hyatt M. Gibbs, Berken Chang, and Rodney C. Greenhow, Optical Orientation of the $^3P_0$ Ground State of Pb^{207}, Phys. Rev. Letters 22, 270 (1969).
2. Frank P. Calaprice, Eugene D. Commins, Hyatt M. Gibbs, Gerald L. Wick, and David A. Dobson, Test of Time Reversal Invariance and Measurements of Positron and Neutrino Asymmetries in Polarized ^{19}Ne Beta Decay (UCRL-18647), Phys. Rev. 184, 1117 (1969).
3. Thomas Fowler and Joseph Yellin, Electric Field Effect in the Resonance Lines of Indium and Thallium (UCRL-19337), Phys. Rev. A1, 1006 (1970).
4. Abiondun F. Oluwole, Stephen G. Schemlling, and Howard A. Shugart, Nuclear Spins, Nuclear Moments, and Hyperfine Structures of ^{69}Ge and ^{75}Ge, and $^3P_2$ Hyperfine Structure of ^{71}Ge (UCRL-19395), Phys. Rev. C2, 228 (1970).
5. Richard Marrus, Edmond C. Wang, and Joseph Yellin, Atomic Beam Measurement of the Potassium 39-41-42 Isotope Shift, UCRL-19520, Dec. 1969.
6. Stephen G. Schmelling, Vernon J. Ehlers, and Howard A. Shugart, Nuclear Magnetic Moment, Hyperfine Structure, and Hyperfine Structure Anomaly of ^{196}Au (UCRL-19443), Phys. Rev. C2, 225 (1970).
7. Richard Marrus and Robert W. Schmieder, Observation of the Magnetic Dipole Decay of the $2\,^3S_1$ State of Helium-Like Si XIII, S XV, and Ar XVII (UCRL-19483, Feb. 1970), submitted to Physics Letters.
8. J. R. Calaprice and F. P. Calaprice, Marking Animals with Micro-Tags of Chemical Elements for Identification by X-Ray Spectroscopy, Journal of the Fisheries Research Board of Canada 27 [2], 317 (1970).

9. Robert W. Schmieder, Matrix Elements of the Quadratic Stark Effect on Hyperfine Structure (UCRL-19560, Feb. 1970), submitted to Am. J. Phys.

10. Joseph Yellin, Hyperfine Structure of Gallium 69 in Crossed Electric and Magnetic Fields (UCRL-19598, May 1970), submitted to Phys. Letters.

11. Hyatt M. Gibbs, Berken Chang, and Rodney C. Greenhow, Polarization of Pb Vapor. I. Orientation of the $^3P_0$ Ground State of Pb^{207}, Phys. Rev. 188, 172 (1969).

EXPERIMENTAL PHYSICS

George H. Trilling and Gerson Goldhaber in charge

K^+p INTERACTIONS AT 9 GeV/c

Alexander Firestone, Chumin Fu,
Gerson Goldhaber, and David Lissauer

We have completed the study of approximately 230 000 stereo exposures of K^+p interactions at 9 GeV/c. The film was taken at the Brookhaven National Laboratory 80-in. hydrogen bubble chamber exposed to a 9-GeV/c rf-separated K^+ beam using the Berkeley camera system. The film was taken in two stages: October 1966 and January 1968. In addition to the work on this experiment already published (a list of eleven references is included in the Nov. 1968 through April 1969 Semiannual Report, UCRL-18877, page 61 and the first two references in the May through Oct. 1969 Semiannual Report, UCRL-19415, page 84), we have, in the past six months, published work on the final three projects.

(1) We have studied the reaction $K^+p \rightarrow K^0\pi^+p$ and note that the reaction proceeds entirely through K^*_{890}, K^*_{1420}, and Δ^{++}_{1236} resonance production. We show the spin parity of the K^*_{1420} to be $J^P = 2^+$, with 18% pseduoscalar and 72% vector exchange in its production, the same proportion as for K^*_{890} production. We present data on the cross sections, spin density matrix elements and angular distributions, and note the cross sections for $K^+p \rightarrow K^*_{890}p$, $K^*_{1420}p$, and $K^0\Delta^{++}_{1236}$ appear to fall more rapidly with incident momentum than the predictions of a simple Regge-pole exchange model. This work has been published in Nuclear Physics.[1]

(2) We have analyzed reactions of the type $K^+p \rightarrow \bar{Y}NN(\pi)$, where $\bar{Y}$ refers to a $\bar{\Lambda}$ or $\bar{\Sigma}$ antihyperon, $K^+p \rightarrow \overline{\Xi^-}YN(\pi)$, and $K^+p \rightarrow K^+p\bar{p}p$. With twice the data previously reported, we observed again an enhancement in the $\bar{\Lambda}N$ system at M = 2240 MeV, and also observe this enhancement in the non-exotic $\overline{\Sigma^\pm}N$ final states. Cross sections and production characteristics of all the final states involved are presented. This work has been published in Nuclear Physics.[2]

(3) We have performed an exhaustive study of the final state $K^+\pi^-\Delta^{++}$ in reaction $K^+p \rightarrow K^+\pi^-\pi^+p$ and observe after suitable background cuts a break in the t' distribution at $|t'| \approx 0.05\ (\mathrm{GeV/c})^2$. The sharp forward peak is demonstrated to result from pion exchange and the flatter slope from other meson exchanges. We study the t' distributions, $K\pi$ and Δ^{++} decay angular distributions, spin-density matrix elements, the $K\pi$ asymmetry, and the $K\pi$ mass spectrum. Results on possible s-wave K^* resonances are presented. This work has also been published in Nuclear Physics.[3] In addition, a study of this reaction involving a double Regge-pole-exchange model has been submitted to Physical Review.[4]

1. V. Gordon Lind, G. Alexander, A. Firestone, C. Fu, and G. Goldhaber, Nucl. Phys. B14, 1 (1969).
2. D. Lissauer, G. Alexander, A. Firestone, and G. Goldhaber, Nucl. Phys. B18, 491 (1970).
3. C. Fu, A. Firestone, G. Goldhaber, and G. H. Trilling, Nucl. Phys. B18, 93 (1970).
4. C. Fu, Double Peripheral Model Analysis of the Reaction $K^+p \rightarrow K^+\pi^-\Delta^{++}_{1236}$ at 9 GeV/c (UCRL-19807), Phys. Rev. (to be published).

K^+D INTERACTIONS AT 12 GeV/c

Alexander Firestone, Gerson Goldhaber, and David Lssauer

We have continued scanning and measuring the 525 000 stereo exposures of K^+D interactions at 12 GeV/c taken in April 1969 at the SLAC 82-in. deuterium bubble chamber, exposed to a 12-GeV/c rf-separated K^+ beam. Since the total number of events in the film is about 850 000, we have restricted our attention at first to events with (1) a visible K^0 decay, or (2) any three-pronged event, or (3) any four-pronged event with at least one stopping track. This yields about 250 000 events to be measured. In addition we are scanning for anti-omega candidates, which are characterized by a vee coming from a charged decay. We have measured the cross sections for the reactions $K^+d \rightarrow K^0pp$, $K^0pp\pi^0$, $K^0pn\pi^+$, $K^+\pi^-pp$, $K^+\pi^+\pi^-d$, and $K^0\pi^+\pi^-pp$.

(1) In the final state $K^+\pi^+\pi^-d$ we observed production of K^*_{890}, ρ^0, Δ^{++}_{1236}, and the Q enhancement. Preliminary statistics are inadequate to permit a statement about the splitting of the Q. We expect eventually to obtain over 1500 events in the final state $K^+\pi^+\pi^-d$.

We have studied the three charge exchange reactions, $K^+n \rightarrow K^0p$, $K^+\pi^-p$, and $K^0\pi^+\pi^-p$ and three publications on these reactions are either published or soon to be published.

(2) We have measured the differential cross section for the elastic charge exchange reaction $K^+n \rightarrow K^0p$ and have found it to be (i) identical to the differential cross section for the line-reversed reaction $K^-p \rightarrow \overline{K^0}n$ at 12 GeV/c and (ii) in agreement with the predictions of the Regge-pole model of Rarita and Schwarzschild. We also find that (iii) the forward scattering amplitude is essentially real, and that (iv) the cross section for this reaction as a function of incident momentum is identical to that for the reaction $K^+p \rightarrow K^0\Delta^{++}$ beyond threshold effects. Data (i) and (iii) above are powerful evidence for strong ρ-A exchange degeneracy. This work has been published in Physical Review Letters.[1]

(3) We have completed a major study of the region of the $K^*(1420)$ in the reactions $K^+n \rightarrow K^+\pi^-p$, and $K^+n \rightarrow K^0\pi^+\pi^-p$. In the reaction $K^+n \rightarrow K^+\pi^-p$ we report the existence of a $J^P = 0^+$ or 1^- object in the region of the $K^*(1420)$ that also decays into $K^+\pi^-$. This object appears as a shoulder on the low-mass side of the $K^*(1420)$, but is most easily seen through a study of the decay angular distributions in this region. Its mass is about $M \approx 1360$ MeV and it has a width $\Gamma \approx 60$ MeV. In addition we have measured the branching ratios for the decay of the $K^*(1420)$ into the states $K\pi$, $K^*(890)\pi$, and $K\rho$. Furthermore we have presented evidence for a $K^*_N(1250)$ resonance with mass $M = 1247 \pm 5$ MeV, width $\Gamma = 20^{+9}_{-6}$ MeV.[2]

A preliminary version of this work has been submitted to the XVth International Conference on High-Energy Physics, Kiev, 1970.[4]

1. A. Firestone, G. Goldhaber, A. Hirata, D. Lissauer, and G. H. Trilling, Phys. Rev. Letters 25, 958 (1970).
2. A. Firestone, G. Goldhaber, and D. Lissauer, Evidence for a Narrow K^*_N Resonance at 1250 MeV, UCRL-20091.
3. A. Firestone, G. Goldhaber, and D. Lissauer, Study of the $K^*(1420)$ in K^+d Interactions at 12 GeV/c, to be submitted to Nuclear Physics B.
4. A. Firestone, G. Goldhaber, and D. Lissauer, K^{*0} Production in K^+d Interactions at 12 GeV/c, contribution to the XVth International Conference on High-Energy Physics, Kiev, USSR, 1970.

π^+p INTERACTIONS AT 3.7 GeV/c

Gerald S. Abrams, Keith W. J. Barnham, W. Ralph Butler, Donald G. Coyne, Gerson Goldhaber, Bronwyn H. Hall, Jimmy N. MacNaughton, and George H. Trilling

We are continuing analysis of the data from the 180 000-picture sample of π^+p interactions. The experiment was done in the LRL 72-in. hydrogen bubble chamber. One-third of the events have been checked by a physicist and remeasured to a convergent final status. The remaining two-thirds (excluding strange particles) were processed by a new program designed to closely simulate the action of the physicist, using the FSD (Flying-Spot Digitizer) ionization information. Remeasurements on the remaining film were performed and final event summary tapes were prepared.

New information since our last report follows:

1) Strange particle production: All strange particle events have now been measured, remeasured, and examined at a scan table. Cross sections for observed reactions have been compiled. Special attention is being given to the final states, to search for the less common decay modes of particles such as A_2.

2) The analysis of $\pi^+p \to \pi^+\pi^0p$ has given preliminary cross sections on the production of ρ as functions of ρ decay angle and momentum transfer to the ρ. The possibility of interference between ρ, N^*, and diffractive processes is under study.

3) Much effort has been expended on the analysis of ρ^0-ω interference in the reactions $\pi^+p \to \Delta\rho^0$, $\pi^+p \to \Delta\omega$, as manifested on the $\pi^+\pi^-$ invariant mass distribution. The results are now published in Physical Review Letters 23, 1351 (1969) and provide initiative to study this effect further in both our data and independent reactions. The destructive interference observed has been interpreted by a theory of A. S. Goldhaber et al., but apparently these experimental and theoretical results jointly suggest a different phase in the analysis of the effect quoted by the Orsay group in the reaction $e^+e^- \to \pi^+\pi^-$.

4) The A_2 structure problem has now been updated to include our total sample of

$$\pi^+p \to p\,A_2$$
$$\hookrightarrow \rho^0\pi^+ \to \pi^+\pi^-\pi^+$$

and the presence of structure is still not unambiguous. A spin-parity analysis will be attempted. Possible interferences with $p\pi^+ \to \Delta^{++}\rho$ are being investigated.

5) $\pi^+p \to \pi^+p$ and $\pi^+p \to \pi^0\Delta^{++}$. Some preliminary studies of these reactions were car-carried out. It was discovered that the proton contamination is important here. It is anticipated that the difficulty can be greatly reduced by work in progress on subtraction of proton contamination.

6) The production mechanisms of $\rho^0\Delta^{++}$ and $\omega\Delta^{++}$ were studied via analyses of decay and production angular distributions. Strong support for Regge-pole-type models was found for both reactions [published in Phys. Rev. 25, 617 (1970)].

7) The study of production mechanisms was extended to the reactions $\Delta^{++}f$, $\Delta^{++}\eta$, and $\Delta^{++}\eta'$. Again, simple Regge models appear capable of describing the data.

8) A study has been made of the reaction $\pi^+p \to \Delta^{++}A_2^0$ at 3.7 GeV/c. Some evidence is seen for a dip in the differential cross section for this reaction at $t \approx -0.6\ (\mathrm{GeV})^2$, which is near the nonsense wrong signature point $\alpha_\rho = 0$ of the ρ trajectory. A study of the $\pi^+\pi^-\pi^0$ and $p\pi^+$ mass spectra as a function of t and t' indicates that the A_2^0 and Δ^{++} signals are weak near this t value. Investigation of the production mechanism of the A_2^0

from the study of its decay angular distribution is complicated by background problems.

Further analysis of this channel is continuing.

LOW-ENERGY $\bar{K}N$ INTERACTIONS AND ABSOLUTE K^0_{e3} DECAY RATE

J. A. Kadyk, J. H. Chan, G. H. Trilling, and G. Goldhaber

The remeasure of the low-energy K^-p interactions is essentially complete and ready to be combined with the rest of the K^-p and K^0_2p interaction data for a final analysis of the $I = 1$ $\bar{K}N$ interactions. We have made a Monte Carlo simulation of the K^0_2p interactions and find that a small but appreciable correction to certain reactions should be made because of the method used for fitting the K^0_2 line-of-flight to the external target. After a search for other possible biases, none was found. It is expected that final values of the low-energy interaction parameters will soon be obtained by using the K-matrix formalism as well as the scattering length determination.

As one of the results of the above analysis, an accurate value for the $\Lambda\pi$ cross section will be obtained, which will be used for normalization purposes to obtain from the same film the absolute rate for the decay $K^0_2 \rightarrow e\pi\nu$.

STUDY OF Λp AND Λd INTERACTIONS IN THE MOMENTUM RANGE 300 TO 1500 MeV/c

J. A. Kadyk, G. H. Trilling, G. Alexander, J. H. Chan, and P. J. Gaposchkin

The 25-in. hydrogen bubble chamber was used to obtain data for study of Λp and Λd interactions in the range of Λ momenta approximately 300 to 1500 MeV/c. The rate of Λ production was enhanced by exposing an internally mounted platinum plate to a K^- beam of 1.5 and 1.9 GeV/c momentum. Analysis of the Λp interactions is virtually complete, and a preliminary analysis of the Λd reactions is in progress. Reports on results from both experiments were submitted to the International Conference on High Energy Physics at Kiev, USSR, August 1970.

Approximately 245 examples have been obtained of fits to Λp interactions, consisting of about 180 elastic scatters, 50 $\Lambda p \rightarrow \Sigma^0 p$ reactions, and 15 $\Lambda p \rightarrow \Lambda p \pi^0$ reactions. All but two events have unambiguous fits. From the observed free Λ decays a Λ path-length distribution was derived, leading to determinations of cross sections for these reactions as a function of energy. No strong evidence is seen for a reported Λp resonance in the neighborhood of 620 MeV/c, although the statistical significance is too weak to reach any definite conclusions. However, an upper limit of about 3.5 MeV/c can be placed on the width of the resonance if it exists. Strong contributions from P-wave, and possibly also D-wave, are needed above the $\Sigma^0 p$ threshold in all reactions in order to explain the angular distributions as well as the magnitude of cross sections that rise well above the S-wave unitarity limit.

The data from the experiment on Λd interactions appears, in general, to be compatible with that of the Λp interactions, although the sample of data is more limited since only about 90 000 pictures were taken. An important effect observed in the reactions appears to be the secondary interactions of Σ^- within the deuteron where it was produced, resulting in a change of the angular distribution, and of the cross section $\Lambda n \rightarrow \Sigma^- p$. The rescan of the film is under way, and a final analysis will begin soon.

Λp INTERACTIONS IN THE MOMENTUM RANGE 0.5 TO 5 GeV/c

J. A. Kadyk, G. H. Trilling, and
J. M. Hauptman

Preparations are in progress for an experiment at SLAC to study Λp interactions up to about 5 GeV/c Λ momentum. This experiment will be done by using the 82-in. hydrogen bubble chamber, with an internally mounted platinum plate exposed to a 12-GeV/c K^- beam, a technique similar to that described previously for experiments studying Λ interactions at lower energies. Approval was obtained for 0.5 million pictures, and a test run is scheduled for July 1970. An estimated 1500 elastic scatter events will be obtained, as well as numerous examples of inelastic events, with a mean Λ momentum of about 2.5 GeV/c. Cross sections as a function of energy will be determined by using the free Λ path length derived from observed decays, and angular distributions for the various reactions will also be analyzed. This experiment should contribute about an order-of-magnitude increase of data available in this energy region.

PUBLICATIONS AND PAPERS

1. D. Lissauer, G. Alexander, A. Firestone, and G. Goldhaber, Antihyperon and Antiproton Production in K^+p Interactions at 9 GeV/c (UCRL-19408), Nucl. Phys. B18, 491 (1970).

2. C. Fu, A. Firestone, G. Goldhaber, and G. H. Trilling, The $K\pi$ System in the Channel $K^+\pi^-\Delta^{++}$ at 9 GeV/c (UCRL-19427), Nucl. Phys. B18, 93 (1970).

3. R. W. Bland, M. G. Bowler, J. L. Brown, G. Goldhaber, S. Goldhaber, J. A. Kadyk, V. H. Seeger, and G. H. Trilling, the K^+p Interaction from 864 to 1585 MeV/c; Angular Distributions for Inelastic Scattering (UCRL-19357), Nucl. Phys. B18, 537 (1970).

4. D. G. Coyne, The "Real" and "Imaginary" Parts of the Inconsistency in $\rho^0\omega$ Interference (UCRL-19450), talk given at APS Winter Meeting at UCLA, December 29-31, 1969.

5. G. S. Abrams, K. W. J. Barnham, W. R. Butler, D. G. Coyne, G. Goldhaber, B. H. Hall, and J. MacNaughton, Observation of Regge Pole Effects in $\rho^0\Delta^{++}$ and $\omega^0\Delta^{++}$ Production at 3.7 GeV/c (UCRL-19743), Phys. Rev. Letters 25, 617 (1970).

6. G. S. Abrams and U. Maor, A π-B Exchange Degenerate Model for $V^0\Delta^{++}$ Production (UCRL-19792), Phys. Rev. Letters 25, 621 (1970).

7. A. A. Hirata, G. Goldhaber, V. H. Seeger, G. H. Trilling, and C. G. Wohl, The Reaction $K^+N \rightarrow K^*N$ in the Isospin-O Channel Near Threshold (UCRL-19774), contribution to the Conference on Hyperon Resonances, Duke University, Durham, N.C., April 24-25, 1970.

8. B. H. Hall, R. W. Bland, G. Goldhaber, and G. H. Trilling, K^+p Partial Wave Analysis at 860 to 1210 MeV/c (UCRL-19787), contribution to the Conference on Hyperon Resonances, Duke University, Durham, N.C., April 24-25, 1970.

9. C. Fu, Double Peripheral Model Analysis of the Reaction $K^+p \rightarrow K^+\pi^-\Delta^{++}_{1236}$ at 9 GeV/c (UCRL-19807), Phys. Rev. (to be published).

10. G. Goldhaber, The Search for Z^*'s (UCRL-19832), talk presented at the Conference on Hyperon Resonances, Duke University, Durham, N.C., April 24-25, 1970.

11. A. Firestone, The Q Region of $K\pi\pi$ Mass (UCRL-19846), talk presented at the 1970 Conference on Meson Spectroscopy, Philadelphia, May 1-2, 1970.

12. G. Goldhaber, Experimental Results on the ω-ρ Interference Effect (UCRL-19850), talk presented at the Washington Meeting, American Physical Society, April 27-30, 1970.

To appear in Proceedings of the Second Philadelphia Conference on Meson Spectroscopy, May 1-2, 1970; invited talk at the 1970 Summer School at Herceg-Novi, Yugoslavia.
13. W. R. Butler, Strange Particle Production in π^+p Interactions Near 3.7 GeV/c, UCRL-19845 (Ph. D. thesis).
14. G. H. Trilling, Bubble Chamber Physics in the Seventies (UCRL-19870), talk presented at the International Conference on Bubble Chamber Technology, Argonne National Laboratory, June 10-12, 1970.

PLASMA PHYSICS

C. M. Van Atta in charge

RESEARCH PROGRAMS

The research activity of this group, in plasma physics and related atomic physics, is a part of the controlled-fusion program centered at LRL Livermore. Since complete descriptions of this work are included in the Controlled Thermonuclear Research Annual Report,[1] this section is kept very brief, and some of the problems studied are listed more or less by title only.

Spectroscopic studies for the measurement of high-frequency electric fields in plasma by means of the high-frequency Stark effect have been extended to include magnetic fields (Zeeman effect)[2] and numerical solutions of the Schrödinger equation where perturbation theory fails. Improved agreement between observed and calculated spectra is found. In an application to beam-plasma instabilities, time-resolved observations have recently been successful so that it will be possible to study growth rates.

The analysis of the dense "sheet pinch" by means of laser light scattering is nearly complete. It was found that the presence of neutral hydrogen atoms in the first excited state has to be taken into account because these atoms have a large cross section for the scattering of ruby laser photons.

The response of Langmuir probes in strong magnetic fields has been investigated with the help of our microwave-generated steady-state plasma.[3] The same facility is currently being used to study the propagation characteristics of ion-acoustic waves in mixtures. An experiment on fluctuations and anomalous transport of plasma in a strong magnetic field is continuing.

The laser-plasma experiment has undergone its first real tests. A small, solid particle is dropped through the center of a 4-meter-long vacuum system where it is converted into a plasma by means of a flash of radiant energy from a Q-spoiled ruby laser. The expansion of the resulting plasma in the presence of a strong uniform magnetic field is to be studied. At present, commercial glass beads of 70-μ diameter are being used. Eventually these experiments will be carried out on solid hydrogen.

Developments in theoretical work include the following:

(a) A new formulation of quasilinear theory has been developed.[4]

(b) The study of resonant interaction between particles and waves in finite plasmas has been extended to cylindrical geometry.[5]

(c) Nonlinear analyses of Alfvén waves in uniform but nonisotropic plasmas have been carried out on the basis of Chew-Goldberger-Low and guiding-center theory. Both stable and unstable cases were treated.[6]

(d) The theoretical investigation of the nature and role of external plasma in the end regions of mirror machines is nearly completed. Confinement is found to be affected primarily through the modified plasma potential and through possible instabilities caused by streaming electrons.

The work in atomic physics, which consists almost entirely of measurement of collision and reaction cross sections, included the following items: yields of atomic and molecular neutral beams from H_3^+ breakup in lithium vapor and H_2 and N_2 gases; yields of fast neutral-helium beams; yields of highly excited hydrogen atoms produced at surfaces of thin foils; production of long-lived metastable hydrogen molecules resulting from electron capture in Mg vapor and common gas targets; total cross section for attenuation of H_2 molecules in H_2 gas; and K and L x-ray production cross sections in collisions of relativisitc electrons with heavy atoms.

1. Controlled Thermonuclear Research Annual Report, UCRL-50002-70.
2. W. S. Cooper III and R. A. Hess, Phys. Rev. Letters 25, 433 (1970).
3. I. G. Brown, A. B. Compher, and W. B. Kunkel, Response of a Langmuir Probe in a Strong Magnetic Field, UCRL-20090, August 1970.
4. A. N. Kaufman, Reformulation of Quasilinear Theory, UCRL-19869, June 1970.
5. A. N. Kaufman, Resonant Interactions between Particles and Normal Modes in a Cylindrical Plasma, UCRL-19839, May 1970.
6. B. R. Patterson, Exact Nonlinear Evolution of the Alfvén Mode in the Guiding-Center Model, UCRL-20066, August 1970.

PUBLICATIONS AND PAPERS

1. William S. Cooper III and Roger A. Hess, Spectroscopic Measurment of Electric Fields in a Beam-Plasma Interaction, Bull. Am. Phys. Soc. 14, 1071 (1969).
2. William W. Hicks and William S. Cooper III, Measurement of H and He I Line Profiles in Strong High-Frequency Electric Fields, Bull. Am. Phys. Soc. 14, 1071 (1969).
3. Martin W. Halseth, Particle Transport in a Turbulent Positive Column, Bull. Am. Phys. Soc. 14, 1041 (1969).
4. P. S. Rostler, D. B. Hopkins, A. B. Compher, and I. G. Brown, Suppression of Low-Frequency Fluctuations in a CW Microwave-Produced Plasma, Bull. Am. Phys. Soc. 14, 1029 (1969).
5. I. G. Brown, A. B. Compher, and W. B. Kunkel, Response of a Langmuir Probe in a Strong Magnetic Field, Bull. Am. Phys. Soc. 14, 1012 (1969).
6. D. A. Reilly and W. B. Kunkel, Laser Light Scattering in a Sheet Pinch, Bull. Am. Phys. Soc. 14, 1005 (1969).
7. K. H. Berkner, I. Bornstein, R. V. Pyle, and J. W. Stearns, Yields of Highly Excited Deuterium Atoms from Charge-Exchange in Thin Foils, Bull. Am. Phys. Soc. 14, 1009 (1969).
8. K. H. Berkner, S. N. Kaplan, and R. V. Pyle, Cross Sections for K-Shell Ionization of Pd and Au by 2.5- and 7.1-MeV Electrons, Bull. Am. Phys. Soc. 15, 786 (1970).
9. A. Degasperis and A. N. Kaufman, Determination of the Density Profile in a Plasma Cylinder, Bull. Am. Phys. Soc. 15, 97 (1970).
10. Allan N. Kaufman and Toshio Nakayama, The Interactions of Waves and Particles in an Inhomogeneous One-Dimensional Plasma, Phys. Fluids 13, 956 (1970).
11. Norman W. Albright, Quasilinear Stabilization of the Transverse Instability, Phys. Fluids 13, 1021 (1970).
12. Martin W. Halseth and Robert V. Pyle, Turbulence in the Positive Column, Phys. Fluids 13, 1238 (1970).
13. Klaus H. Berkner, Robert V. Pyle, and J. Warren Stearns, Cross Sections for Electron Capture by 0.3- to 70-keV Deuterons in H_2, H_2O, CO, CH_4, and C_8F_{16} Gases, Nucl. Fusion 10, 145 (1970).
14. Ian G. Brown, Alan B. Compher, and Donald B. Hopkins, Rev. Sci. Instr. 41, 600 (1970).
15. Peter S. Rostler, Donald B. Hopkins, Alan B. Compher, and Ian G. Brown, Suppression of Fluctuations in a Microwave-Produced Plasma by a Feedback Technique, UCRL-19471 Rev., June 1970.

16. William S. Cooper III and William W. Hicks, High-Frequency Stark Effect in Helium I and Its Application in Plasma Diagnostics, UCRL-19728, April 1970.
17. Ian G. Brown, Alan B. Compher, Kenneth W. Ehlers, Donald B. Hopkins, Wulf B. Kunkel, and Peter S. Rostler, Feedback-Controlled Steady-State Plasma (UCRL-19783, April 1970), Plasma Phys. (to be published).
18. William S. Cooper III and Roger A. Hess, Spectroscopic Measurement of the Frequency, Intensity, and Direction of Electric Fields in a Beam-Plasma Interaction by the High-Frequency Stark-Zeeman Effect (UCRL-19801, May 1970), Phys. Rev. Letters 25, 433 (1970).
19. Kenneth W. Ehlers and Ian G. Brown, Rejuvenation of Helium-Neon Lasers (UCRL-19773, April 1970), Rev. Sci. Instr. (to be published).
20. Allan N. Kaufman, Resonant Interactions between Particles and Normal Modes in a Cylindrical Plasma, UCRL-19839, May 1970.
21. Allan N. Kaufman, Reformulation of Quasilinear Theory, UCRL-19869, June 1970.

25-INCH HYDROGEN BUBBLE CHAMBER

Wilson M. Powell, John A. Kadyk, and Glenn J. Eckman in charge

The 25-inch hydrogen bubble chamber operated through this report period with no major difficulties. A total of 2 131 680 pictures were taken for eight different experiments.

INTERNAL TARGET

During the seven-week shutdown of the Bevatron in December and January, the yttrium-sulfate target for the University of Massachusetts experiment was installed in place of the platinum target in the movable assembly inside the chamber.

OPERATION

Approximately 600 000 pictures were taken in the triple-pulse mode (three chamber expansions per Bevatron pulse). The rest were taken in the double-pulse mode. Tests were conducted at four and five expansions per Bevatron pulse with satisfactory results. However, chamber operation was limited to three expansions because of Bevatron RBE limitations.

It should be noted that in the last three weeks of operation (in the triple-pulse mode), 513 097 pictures were taken. This is equivalent to $\sim 8.9 \times 10^6$ pictures per year.

The chamber terminated operations on May 25, 1970 after six and one-half years as a physics research tool at Berkeley. Over 16×10^6 expansions of the chamber were recorded and 9 298 597 pictures were taken during its lifetime.

The system was disassembled and many of the main components were loaned to SLAC to be utilized in the construction of a rapid cycling hydrogen bubble chamber facility.

FILM PRODUCTION

The following is a breakdown by experiment number* of film production for this period.

Experiment Number	Particles	Rolls	Pictures
72	π^+p	119	199 444
87	π^+p	109	180 259
112	K^+D	29	48 482
115	K^-p	379	635 033
126	K^+p	238	406 090
128	K^-1	65	111 209
	(Yttrium-Sulfate Target In)		
137	π^+p	160	272 301
138	π^+p	165	278 862
	TOTAL	1264	2 131 680

*The experiment number as assigned by the Bevatron Scheduling Committee.

HEALTH PHYSICS

H. Wade Patterson in charge

RADIATION DAMAGE STUDIES IN SPACECRAFT VIEWING PORT GLASS

A. J. Miller and L. D. Stephens

Under a contract with Tinsley Laboratories, Berkeley, an experiment has been completed using the Electron Linac as a radiation source to simulate Van Allen Belt radiation. Samples of glass proposed for spacecraft viewing ports were exposed to this radiation for study.

Radiation doses were given these samples to correspond to specific time intervals in certain regions of the radiation belts. Several tests of the glass were then made. These included changes in optical coatings, transmission, absorption, and reflection. Doses of radiation sufficient to render the glass unusable for its intended purpose were determined. The results will be used by mission planners to specify operating intervals and shielding requirements with a reasonable degree of accuracy.

NEUTRON SPECTROMETER

Alessandro Rindi and Chun Bin Lim

Our spectrometer is a device which measures the energy spectrum of stray neutrons of energy between 25 and 300 MeV around the accelerators, and is made of a stack of 12 units, each unit consisting of a spark chamber, a plastic scintillator, and a polyethylene n-p converter.

Operation of the spectrometer is based on neutron elastic scattering on H in the above energy range. We measure the recoil proton spectrum with the spectrometer and later unfold the neutron spectrum using the relation between the recoil proton spectrum and the neutron energy spectrum through the n-p differential cross section and scattering kinematics. Therefore, our job can be roughly divided into two categories: first, making the above instrument, and next, developing the unfolding process appropriate for the above energy range.

For the first category, progress so far is as follows: After a broad survey of various spark-chamber designs, we made our own spectrometer design best suited to our experiment. The first test chamber was made and checked successfully in its functioning. Now 12 chambers with very few modifications have been ordered and are in the assembly stage. The chambers will be completed around the beginning of November. We are now studying the electronics logic to be used with them.

For the second category, we performed a very detailed analysis of possible physical reactions and the expected shape of the proton recoil spectrum. The major problem in the analysis was allowing for the nonisotropic nature of the stray neutrons in the above energy range and the high probability of the recoil proton escaping. We developed a method incorporating the anisotropy of the neutron angular shape and escape probability of recoil protons in the unfolding process by simulating the neutron transport inside the spectrometer using the random-sampling technique. The

output from this will be combined with n-p elastic differential scattering cross sections to generate the kernel matrix elements needed in the numerical version of the unfolding equation. The unfolding equation will be solved using either a direct or an iteration technique.

PUBLICATIONS AND PAPERS

1. William S. Gilbert, Klaus Goebel, H. Wade Patterson, and Alan R. Smith, Concrete Activation Experiment at the Bevatron, UCRL-19368, December 1969.
2. H. Wade Patterson, Jorma T. Routti, and Ralph H. Thomas, What Quality Factor?, UCRL-19382, April 1970.
3. Jorma T. Routti, SAMPO, A Fortran IV Program for Computer Analysis of Gamma Spectra from Ge(Li) Detectors, and for Other Spectra with Peaks, UCRL-19452, October 1969.
4. Klaus Goebel and J. Ranft, Radiation Measurements Around a Beam Stopper Irradiated by 19.2-GeV/c Protons, and Neutron Energy Spectra by Monte Carlo Nucleon-Meson Cascade Calculations, in Proceedings of the Second Symposium on Accelerator Dosimetry and Experience, Stanford, California, November 5-7, 1969, p. 394.
5. Lloyd D. Stephens and Alvin J. Miller, Radiation Studies at a Medium Energy Accelerator, in Proceedings of the Second Symposium on Accelerator Dosimetry and Experience, Stanford, California, November 5-7, 1969, p. 459.
6. Roger Wallace, Gerald M. Litton, and Palmer G. Steward, Stopping Power, Range, and Terminal Ionization of Any Nucleus with 0.01 to 500 MeV/amu in Any Non-Gaseous Material, Including Nuclear Effects, in Proceedings of the Second Symposium on Accelerator Dosimetry and Experience, Stanford, California, November 5-7, 1969, p. 692.

Computing and Data Handling

MATHEMATICS AND COMPUTING

James A. Baker in charge

The Mathematics and Computing Group provides advanced computing services to the Laboratory's scientific research and engineering groups. These services include operating the Laboratory's central computing facility of two multiprogrammed CDC 6600's, several smaller IBM computers, and associated peripheral equipment and instrumentation. The systems programming staff develops and maintains the software for these computers, while the applications programming staff provides programming support to the many Laboratory physicists and other researchers who use computers for data collection and analysis. In addition, the Mathematics and Computing Group carries on a modest program of research in mathematics and computer science.

During the period of this report (November 1969 through June 1970), members of the Mathematics and Computing Group provided programming and mathematical consulting services for Laboratory reserach groups and continued research projects in mathematics and computer science. Their projects may be divided into four general classifications:

I. Applications Programming
  A. Physics
  B. Nuclear Chemistry
  C. Accelerator and Magnet Design
  D. Biomedical Applications
  E. Miscellaneous
II. Systems Programming
III. Computer Operations
IV. Research in Mathematics and Computer Science.

The following pages summarize the recent work of the Mathematics and Computing Group in the above areas.

I. APPLICATIONS PROGRAMMING

A. PHYSICS

For Powell-Birge Group

Herbert C. Albrecht, Joan Tyson, John Visser, and Edna Williams

Because the IBM 7044 does not contain enough core memory to satisfy the present needs of COBWEB[1] users, COBWEB has been divided into segments and now operates as an overlay system. This provides increased capacity for computations without noticeably lengthening the response time at the measuring machines.

To implement the segmenting of COBWEB, a 6.4-million-bit disc was attached to the IBM 7044 computer through the Channel B Direct Data connection. This disc consists of 64 tracks; each track is divided into 8 sectors of 328 36-bit words, giving a total of 161 536 words.

The COBWEB utility package has been rewritten, with COBEDIT[2] and BOOKIE[3] included as new utility functions. These large CDC 6600 programs are now undergoing debugging and it is expected that they will soon be running in real time with COBWEB on a production basis.

1. Herbert C. Albrecht, Eugene P. Binnall, Robert W. Birge, Myron H. Myers, and

P. Wes Weber, COBWEB: Data Reduction System, UCRL-18528, Oct. 1968.
2. PDSR (Physics Division Semiannual Report), UCRL-18235, May 1968, p. 76.
3. PDSR, UCRL-17876, Nov. 1967, p. 51.

For Trilling-Goldhaber Group

Emmett Burns, Allen Franklin, Art Habegger, and Bronwyn Hall

All programs have now been converted to utilize the Mass Storage System. Data for all of the existing experiments are stored on this system and are being used by the physicists. The Trilling-Goldhaber version of ARROW[1] has been further optimized with respect to the field length; an execution-control-card processor was written to allow the user to specify certain options more easily without altering his own code.

The master list progrm MLIST1 has been completed and documentation will be ready soon. This program is a bookkeeping system for high-energy-physics events, recording when and where each event was measured, as well as the final status of the event after data reduction has been performed. MLIST1 will allow the physicist to keep track of all events regardless of the data analysis system upon which they are processed.

A similar program, MLIST2, presently almost completed, will take advantage of the Mass Storage System's random access capabilities. This random access enables the user to retrieve in one pass the few events on each data tape which need reprocessing, without reading all 50 to 100 tapes of an experiment.

The bubble chamber analysis program CHAOS[2] was modified to give the user more options. These modifications proved quite useful and are being employed to perform density matrix analysis.

A new neutral beam K_0 experiment was set up for analysis by SIOUX.[3] This included determining the optical (top glass and camera) constants of the SLAC 82-in. bubble chamber, adjusting the magnetic field, and performing an extensive checkout of all parameters.

1. Nancy L. Gould, 6600 Arrow System, Group A Programming Note P-186, May 1969.
2. Derik V. Armstrong, CHAOS, Trilling-Goldhaber Physics Note 141, Oct. 1966, and CHAOS NL 1, Jan. 1968.
3. PDSR, UCRL-18877, May 1969, p. 75.

For Moyer-Helmholz Group

Fredric Gey and Ruth Hinkins

The data acquisition system for the ^{3}He - Gamma Time Reversal experiment has been completed.[1]

A reprogramming effort based on different methods has successfully corroborated the previous assumptions and results of the $\pi^- + {}^3$He experiment.[1]

1. PDSR, UCRL-18619, Nov. 1968, p. 96.

For Crowe Group

Victor Elischer

Work on a PDP-15-based on-line data acquisition system, SCAS, has been started to monitor and accept data from spark chamber experiments.

For Lofgren Group

Donald Zurlinden

In order to comply with a configuration change of film output,[1] programming additions and modifications were made to the programs used for scanning the output from Bevatron experiment No. 67 (K_{E2} branching experiment). This updating is regularly required in order to maintain data production despite variations in film quality, changes in lighting,

and alterations in the size and shape of the sparks observed.

1. PDSR, UCRL-17876, Nov. 1967, p. 53.

Group A

Donald Zurlinden

A new series of programs that scan the spark chamber film output from the SSCM (Small Super Conducting Magnet) balloon experiment has been completed. The programs were written specifically for this experiment, since changes in parameters between spark chamber experiments are so extensive that the 8000-word computer used for scanning film output requires special codes for each experiment.

For Theoretical Physics Group

Esther Schroeder

In a comparison study of nonlinearity in negative mass instability, a variety of different mathematical techniques were used to solve coupled nonlinear ordinary differential equations for the mode amplitudes. The reresults were in excellent agreement, and will later be compared with numerical simulation calculations now under development.

B. NUCLEAR CHEMISTRY

Billie Bearden, Noel Brown, Emmett Burns, Claudette Lederer, and Gerald Litton

Work has been completed on the nonlinear least-squares program FELSPAR,[1] which fits photoelectron spectra to a choice of two peak functions and a choice of two leading tail functions, as well as to a linear background. The program theory and results have been published.[2]

Development has begun of a general-purpose spectral analysis program, SUNDER,[3] of which FELSPAR will be a subset. SUNDER will offer the option of adding spectral calibration, as in photoelectron spectra, and will provide added I/O flexibility.

The CDC 6600 program, PACIFIC, was written to consolidate three different functional forms for the nonlinear least-squares fitting of perturbed angular correlations. This program obsoletes the two earlier programs, COSFIT7[4] and FOREX.[5]

PDP-7 HILAC Operative System

The multidimensional data programs MULTI-D[6] and MULTI-S[7] are being extended to handle variable dimensioned data (from 2 to 8 parameters) and to sort these data onto the disc.

A program is being developed to accumulate a large spectrum (up to 128k channels) on-line on the data disc.

Field-Free-Laboratory Computer-Controlled Spectrometer

Work was started on redesigning the software system in order to utilize the recently acquired disc and tape drive. The disc will be used for program roll-in/roll-out so that a much larger range of counting channels will be available to the experimenter. The tape will contain all of the experiment's data in a format acceptable to the CDC 6600 fitting program.

1. PDSR, UCRL-17876, Nov. 1967, p. 54.
2. C. S. Fadley, Core and Valence Electronic States Studied with x-ray Photoelectron Spectroscopy, UCRL-19535, April 1970, pp. IV-38 through 48.
3. PDSR, UCRL-19415, Dec. 1969, p. 102.
4. PDSR, UCRL-18619, Nov. 1968, p. 98.
5. Ibid., p. 98.
6. Ibid., p. 97.
7. PDSR, UCRL-18877, May 1969, p. 78.

C. ACCELERATOR AND MAGNET DESIGN

Victor Brady, Bruce Burkhart
Thomas Clements, Elon Close, John Colonias, Allen Franklin, Robert Healy, Ardith Kenney, Barbara Levine, and Steven Sackett

Magnet Design

Extensive changes have been made in the magnetostatic code TRIM.[1] The new version has an improve cylindrical algorithm that eliminates inaccuracies near the z axis, as well as a faster and more accurate edit routine. In addition, some effort is being spent to increase the speed and accuracy of the iterative algorithm of this program.

A version of TRIM that can be run remotely via a teletype terminal has also been completed. Remote users at Los Alamos Scientific Laboratory employ this version, both interactively and for remote batch job entry.

A program for the solution of the nonlinear magnetostatic field equations in three dimensions has been started. The algorithm used is described in UCID-3435.[2]

Orbit Studies

Work on a spectrometer design program, GOC,[3] has been completed and now includes a scatter-plot facility which allows the user to design baffles in an air or iron core spectrometer.

Program TRANSPORT[4] has been completed. The calculations for first- and second-order optics have been debugged, and both the on-line and off-line versions are operational.

Program RECYL has been written to calculate orbits of heavy ions in the magnetic field of the 88-in. cyclotron. This program has been used to study the feasibility of injecting 40-MeV Kr^{6+} ions into the cyclotron, stripping 13 electrons, and accelerating the resulting Kr^{19+} to an energy of 550 MeV.

SOTRM, a ray tracing program that generates first- and second-order beam optic matrix elements for particles in a magnetic field, has been completed.[5,6]

The regularly used synchrotron design program SYNCH[7] has been modified to include the calculation of beam envelopes with space charge forces.

Cyclotron Design

Work continues on the modification of the cyclotron code CYDE.[8] This program is being modified to allow calculation of equilibrium orbits in magnetic fields created by calculated trim coil currents or from currents read as input.

Electron Ring Accelerator

The program TERA, designed to simulate ring compression and extraction in conjunction with the Compressor IV experiment was rewritten and modified to accept new coils or revised coil dimensions. It is now able to simulate eddy-current perturbations in a more convenient way.

A program RING for calculating the radiation from a charged ring in any arbitrary cylindrical structure is under development. This code, which is restricted to on-axis rings traveling at constant velocity, solves Maxwell's equations for the H-field produced by the presence of the perfectly conducting structure. The H-field is then integrated through time to give the energy loss.

Miscellaneous Projects

An extended set of CDC 6600 FORTRAN I/O routines featuring field-free input and formatted partial line printing, which is compatible with the usual FORTRAN READ/WRITE routines, has been prepared. A preliminary version was described in UCRL-19422[9] and the final version in UCRL-19413.[10]

Experiments in information retrieval involving the construction and use of inverted files were conducted. Such files would allow a user to do on-line search for documents.

A new version of the mailing-label program has been written; free format input, random disc sorting, automatic addressing, and ID numbering are among the new features.

1. John S. Colonias, TRIM: A Magnetostatic Computer Program for the CDC 6600, UCRL-18439, Aug. 1969.
2. Steven J. Sackett, An Algorithm for the Numerical Solution of the Nonlinear Magnetostatic Field Equation in Three Dimensions, UCID-3435, April 1970.
3. PDSR, UCRL-19415, Dec. 1969, p. 102.
4. John S. Colonias and Arthur C. Paul, On-Line Calculation of Beam TRANSPORT Systems to First and Second Order, UCRL-19414, April 1970.
5. Elon R. Close, SOTRM: A Program to Generate First and Second Order Matrix Elements by Tracking Charged Particles in a Specified Magnetic Field, UCRL-19823, May 1970.
6. Elon R. Close, Generation of First and Second Order Transformation Elements from a Given Magnetic Field, UCRL-19812, April 1970.
7. A. A. Garren and J. W. Eusebio, SYNCH: A Computer System for Synchrotron Design and Orbits, UCID-10153, April 1965.
8. Elon R. Close, CYDE: A Collection of FII Cyclotron Development Codes for Use on the IBM 7094, UCID-2869, Jan. 1967.
9. Elon R. Close, Generalized Runge-Kutta Schemes: A Global Approach to their Parameter Defining Equations, UCRL-19422, Nov. 1969.
10. Elon R. Close, An Extended Set of Fortran Input/Output Routines, UCRL-19463, Feb. 1970.

D. BIOMEDICAL APPLICATIONS

Robert Belshe, Victor Elischer, Robert Fink, Deanna Harrell, Cheryl Herrin, Ruth Hinkins, William Hogan, Harvard Holmes, Mark Horovitz, Martin Itzkowitz, Claudette Lederer, Marjory Simmons, and Kenneth Wiley

For Laboratory of Chemical Biodynamics

Development of the general-purpose spectral analysis program SUNDER[1] has begun, as described above under B. NUCLEAR CHEMISTRY.

Work is continuing as previously described on the CDC 6600 program FORTE,[2] which processes nuclear magnetic resonance spectra collected with the PDP-8. New filters to correct spectral distortion have been added, and the previously reported operations—normalization, filtering, integration, and calculation of Fourier transforms—can now be performed on relaxation time spectra and calculated correlated spectra. Memory requirements for this program have been reduced.

Development of the software system ACQUIRE,[3] a data-acquisition system utilizing a Sigma-2 and a PDP-8L computer, has been started. Progress on the system during the period covered by this report includes the following projects:

1) Preparation of background and utility programs to use as background on the SIGMA-2 computer.

2) Modifications to the XDS software system.

3) Addition to the system by the completion of new system utility routines.

4) Preparation of user library and public library routines.

5) Design and preliminary coding of the major control portions of the data collection system.

6) Complextion of the design and coding of a four-user time-sharing system. Work on various processors for this system has been started.

For Donner Laboratory

A PDP-8 program, MOSSY, was written to acquire data from a Mössbauer spectrometer and display the data on a CRT display console at Donner. The data may then be

output either on the teleprinter or on punched tape, in format acceptable to the BRF (Berkeley Remote Facility) system for remote job submission to the central computer facility.

The Biomedical Group headed by Ernest Dobson received a PDP-12 computer in later 1969. The main purpose of this machine is to collect data from a number of scintillation counters during tracer kinetic studies of the dynamics of the microcirculation in peripheral vascular beds, and to display and analyze this data. The following projects for the PDP-12 have been completed or are in progress:

1) A data break interface has been designed to accept counts from four scintillation counters as input to the PDP-12 memory.

2) A data-acquisition program, DOGGY, has been written which operates the data break interface, provides a real-time display showing the progress of the experiment and the data-collection parameters currently in use, and outputs the data to magnetic tape for processing on the CDC 6600. The first version of DOGGY has been completed and was used for one experiment.

3) A hardware interface was designed to link the PDP-12 with the Kennedy tape unit purchased for use with it.

4) The tape library system developed at the Bevatron was modified for use on the PDP-12 and Kennedry tape unit.

For Biomedical Research

A PDP-8 program, PHA, was written to accumulate and display cell volume distributions for use in cell identification. The PDP-8I is on-line to an instrument that measures the volume of individual cells in a solution.

Work began in April on the software for ISAH, a computer-controlled patient chair for irradiation therapy. A test bed was constructed to simulate the worst-case drive conditions. Electronic equipment, some interface details, and the software approach were checked. Following this, software was designed for a PDP-8L to drive six axes instead of one as in the test bed. The magnetic tape interface has been specified, hardware design has begun, and software is well under way.

The following modifications were made to the existing depth-dose mapping program DOSEM (whose precursor was the previously described program DOSMAP[4]):

1) Ability to define interior bodies (e.g., lungs, spine) of differing densities within a primary body contour.

2) Addition of a filter of arbitrary shape placed in the beam path.

3) Ability to define a target area and compute a variable filter thickness for each angle of irradiation such that the maximum dose will be automatically concentrated within the target.

The program PROBE attempts to delineate inhomogeneities in density in one cross-sectional plane of a body, using only radiation absorption data taken at various angles in the plane. The result is a density map (showing interior bodies or organs) of the cross section for use in radiation therapy.

The programming for the diabetic retinopathy study was completed in January 1970. The MEDPIC[4] system—consisting of MEDPIC, TADEUP (file update/create), TPMERG (file merge), and PDUMP (file point), as well as comprehensive BARB-produced writeup describing each program in the system—were placed on MSS (chipstore). Data tapes for the diabetic retinopathy study were also placed in archival MSS.

Discrete Fourier transforms: A program XARGE has been written around TDFFT[5] that accepts complex matrices in the range 32 × 32 to 1024 × 1024, displays the function before transformation, transforms the array, and displays the results on 35-mm microfilm. There are two versions of XARGE. One produces perspective plots of the functions involved, the other produces contour plots.

An inexpensive video scanning system is being developed to digitize electron micrographs and other data recorded on photographic film. The film is first scanned with a high-resolution television camera. Since the band-width of the real-time television signal produced is too high for direct digital tape recording techniques, the signal is compressed by a sampling method referred to as "slow scan conversion." The individual picture samples are then digitized and recorded on magnetic tape. A program SLOSCN is used to read the tape and reconstruct the picture into a matrix suitable for further processing. At the present time, SLOSCN has been written and debugged. Special interfaces to programs INCOR, XARGE, TDFFT, etc. will be written in the future, after hardware problems dealing with recording and calibration have been resolved.

For Health Physics

Work is underway on a program, GOLUX, to generate and update a library of all known radioactive isotopes and their properties. In connection with this the program GAMAL is being developed to produce a list of all the isotopes, their half-lives, and gamma-ray energies and intensities.

The program FARROW converts modified ASCII code data tapes from a multichannel pulse-height-analyzer gamma-ray spectrometer into packed display code tapes, in a format suitable for use with existing CDC 6600 spectral analysis codes. It also correlates auxiliary data for each run with the actual analyzer measurements.

The program HYINX fits a smooth curve to a set of discrete readings of photographic film exposure density versus intensity of irradiation. The resulting curve is used to process the film-badges of laboratory employees. The fitting section of this program has been rewritten, and the on-line teletype options have been expanded.

Display schemes for information gathered by multiwire proportional chambers are continually being improved. The imaging performance of the chambers is being simulated to increase our understanding of relevant parameteres in the construction of such systems.

Position-imaging work continues at a low level of activity.

1. PDSR, UCRL-19415, Dec. 1969, p. 102.
2. Ibid., p. 101.
3. Robert Fink, ACQUIRE: A Data Acquisition and Analysis System (For the Laboratory of Chemical Biodynamics), Sept. 1969.
4. PDSR, UCRL-17876, Nov. 1967, p. 55.
5. PDSR, UCRL-18877, May 1969, p. 81; also available in the 6600 Program Library.

E. MISCELLANEOUS

Robert Belshe, Mansfield Clinnick, Deanna Harrell, David Jenson, James Miller, Bobby Powell, Marjory Simmons, and Leo Vardas

University of Washington

A PDP-5 data acquisition program, MUON,[1] was written for use with data from the muon depolarization experiment at the 184-in. cyclotron. The program is now being used to collect data from the experiment, write the data on magnetic tape, provide a real-time display of the data as it is collected, generate histograms of event parameters, and perform limit and error checking on all incoming data.

Bevatron PDP-8 Systems Programming

The tape/disc library system has been improved to speed operation and to allow simplified save/recovery techniques. User manuals for the library system programs[2] have been completed and are now available.

Bevatron Motor-Generator Control Program (BMAG)[3]

The operator's manual and detailed description of BMAG have been completed, using the BARB report-writing program. Continuing improvements in BMAG are being made to provide better data logging, more complete fault protection, and several new functions to aid the operator in setting critical control parameters.

Bevatron External Proton Beam Magnet Control (EPB)[4]

A major revision of EPB is now under way that will enable the computer to control a larger number of magnets and allow the operator to adjust each control zone independently. This system makes use of the disc to store program overlays as well as the instanteous values of the magnet control parameters which are needed to implement the independent zone control.

In addition, many smaller changes have been made to EPB to provide more flexible operation and to reduce operator problems.

Physics Division Progress Report

The 6600 FORTRAN program TYPS[5] (for typesetting) was modified to handle Hershey character widths. The PDP-8 program SCRL (for scroll) text and input and editing program was written and debugged. SCRL takes input from a special keyboard, displays it on a Tektronix storage scope, permits insertions and deletions at any point, and makes up output tapes for subsequent processing (either by TYPS, or further editing).

The basic data structure of SCRL was then modified, and preliminary work was done on a PDP-8 program CSCL (chemistry variant of SCROLL).

Information Processing

The ARDIE[6] System has been extended to accommodate data prepared by various input devices, such as Red Keyboard,[7] CRT, PDP-8 computer input editing, and a high-resolution SC 4060 CRT.

The Key Word in Context program KWIC[8] was modified for improved retrieval and sorting efficiency.

The cost projection program COSTAL[9] has been expanded to include all scientific and support purchases. COSTAL compares Laboratory expenditures and commitments to purchase (made by the Accounting Department) with information from Stores on goods received. The result is a 9-week projection of anticipated purchase commitments. This cost projection program was previously used only for Physics Division purchases.

Utility Routines

A new BLIMP[10] compiler, which incorporates the macro and compile time facilities of PROMAC[11] as well as improved source language syntax, has been completed. This compiler will be used primarily for systems software development and non-numerical applications.

Several new binary output formats were added to the PDP-9 assembler, and the option of ones complement or twos complement numbers was included.

Printed Circuit Artwork

A flexible Vista CRT input system has been incorporated into PUZZLE,[12] a program to aid in the design of printed circuit cards. Also, modifications to the routing algorithms and to the input driver were made to permit

the design of "denser" circuit boards. It is now possible to specify lines anywhere on a grid of points 0.05 in. apart, whereas the previous minimum point separation was 0.1 in.

1. PDSR, UCRL-19415, Dec. 1969, p. 106.
2. Program writeups are available from Bob Belshe, X6339.
3. PDSR, UCRL-19415, Dec. 1969, p. 103; also available from Bob Belshe, X6339.
4. PDSR, UCRL-19415, Dec. 1969, p. 103
5. Loren P. Meissner, Mansfield L. Clinnick, and Robert A. Belshe, Low-Cost Source Data Terminal for Technical Text, UCRL-19390, Feb. 1970.
6. PDSR, UCRL-19415, Dec. 1969, p. 106.
7. Ibid., p. 107.
8. Ibid., p. 106.
9. PDSR, UCRL-17544, May 1967, p. 42.
10. PDSR, UCRL-17876, Nov. 1967, p. 59.
11. PDSR, UCRL-18619, Nov. 1968, p. 105.
12. D. A. Harrell and R. Zane, Computer Aided Design of Printed Circuit Artwork, UCRL-18172, April 1968.

II. SYSTEMS PROGRAMMING

Eric Beals, William Benson, Jerry Borges, Douglas Brainard, Roy Carlson, Robert Fink, Richard Friedman, William Gage, Arthur Habegger, Nigel Harrison, Walter Hutchinson, David Jenson, Joyce Johnston,* Jeremy Knight, Michael Long, Samuel Penny, Gregory Richterich,* David Stevens, Robert Tracy,* and Donald Zurlinden

ASOP (The 6411 System)[1]

1) A DEBUG card was introduced to prevent nontest jobs from being run on a CDC 6600 undergoing system test. In particular, this allows the output from the test jobs to be printed on the 6411, thus permitting the 6600 to return to normal services more rapidly after the test period.

2) The implementation of an "empty/fill" utility (which allows existing input and output queues to be saved on tape and restored from tape when the system must be taken down) was begun.

BKY (The CDC 6600 System)

The following three projects were discussed in the previous progress report;[2] their current status is:

1) The 64-control-point system will be known as BKY40, and entered the final debug stages in July 1970.

2) I/O revisions are about 50% complete. The central processor portions and all unit record work has been completed; new tape drivers remain to be done.

3) Design of the automatic tape-paging system is complete, and programming is under way. The system has been slightly modified to permit installation under BKY40 without waiting for RECC.

An effort is under way to reduce the amount of output printed. This will include compiler changes to compact what output is printed, a usable implementation of the LIST/NOLIST option for RUNF and FTN, and a parametrized EXIT card which will provide more flexible error handling (including the ability to avoid unwanted DMP's). Of these projects, the first has been completed, the second is just beginning, and the third has not yet begun.

A dynamic disc buffering scheme to improve disc channel utilization is in an early stage of planning.

MSS and PSS (the Chip Store and Data Cell Systems, Respectively)

The effort[3] to unify the control languages for these two systems is proceeding satisfactorily; the MSS portion is about 60% complete, the PSS portion about 75% complete. The use of both systems is increasing—1200 boxes have been entered into active storage on MSS, and all 10 cells on the data cell drive have been taken over by PSS. The new disc-pack access methods have been implemented and a PSS back-up table is now kept on the data cell itself to facilitate recovery.

A technical paper[4] outlining the selection of the chip store and the specification and

implementation of MSS will be presented at the Fall Joint Computer Conference, Houston, Texas, in November 1970.

Interactive Applications

The interface linking the BRF (Berkeley Remote Facility) system[5] and PSS (the data cell system) has been expanded to include several features requested by users, the principal one being implementation of an ↑ERASE subsystem to permit on-line erasure of PSS subsets and libraries.

The interactive output scanning package[6] was completed; it provides console users with on-line access to their print files for debugging purposes. After scanning the output, the user may elect either to print the file or to cancel it.

PTSS, a new interactive system developed by Andrew Tannenbaum (Space Sciences Laboratory) with the assistance of William Benson, has been installed. PTSS is complementary to BRF, and is principally dedicated to on-line debugging of FORTRAN programs. A users' guide is available as subset WRITEUP on PSS library PTSS.

RECC (Remote Equipment Control Computer)

Because of extensive changes in the hardware configuration caused by persistent disc problems and the substitution of a simpler multiplexor than the one originally planned, the RECC system was completely redesigned. Coding and checkout of the new design are now about 15% complete.

Remote Batch

A pilot remote batch system has been specified, and implementation will begin shortly. The system will utilize a "dumb" multiplexing small computer (that is, it will handle message-switching and file-direction, but performs no formatting or translation tasks for the remote stations). Concurrently, a survey of potential customers is being conducted to determine whether the probabe demand can best be met by upgrading the pilot system, or by purchasing a more comprehensive system.

Computer Acquisition

A set of all-FORTRAN benchmarks was prepared for use in the computer selection process.

The design seminars mentioned in the previous report[7] have been concluded, after proposing (for both computers under consideration) tentative solutions to the problem of software systems for the resulting computer complex, as well as detailed hardware configurations.

A survey of the types of Computer Output to Microfilm recorder (COM) equipment now available was undertaken in preparation for composing the Request for Proposals for a COM system to support the new large-scale computer.

Miscellaneous

1. A maintenance evaluation program from Kirkland AFB was adapted for use at LRL.

2. In April 1970, the RUNF compiler replaced RUN as the most popular FORTRAN compiler at LRL.

3. A disc I/O simulation model was developed to assist in the design of the proposed dynamic buffering system for the CDC 6600's.

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*CDC programming personnel.

1. Sam Penny, ASOP: Attached Support Operating System, Math & Computing Memo No. 303, Nov. 1967; available in the Computer Center Library.
2. PDSR, UCRL-19415, Dec. 1969, p. 104.
3. Ibid.
4. Ibid.

5. Samuel J. Penny, Robert Fink, and Margaret Alston-Garnjost, Design of a Very Large Storage System, UCRL-19757 Rev., June 1970.
6. James Burkhard, Niegel Harrison, and Edward Romascan, The Berkeley Remote Facility (BRF) User's Guide, UCID 3339 (updated through July 1970).
7. PDSR, UCRL-19415, Dec. 1969, p. 104.

III. COMPUTER OPERATIONS

Paul A. Rhodes and F. Marvin Atchley

The tape library has been converted from a canister to a tape seal system; this has increased the storage capacity of the library from 20 000 to 40 000 reels of tape. A new tape-fetching system was installed, causing a 75% reduction in tape fetches from the tape vault and decreasing tape-handling errors.

All of our CDC 607 tape drives have now been modified to 607R models, which feature a radiused read/write head for improve reliability and improved error-detection circuitry.

Plans for the physical requirements of an additional large-scale computing system are being developed.

IV. RESEARCH IN MATHEMATICS AND COMPUTER SCIENCE

Paul Concus, Fred Gey, David Jenson, Loren Meissner, Mansfield Clinnick, Grove Nooney, and Jonathan Young

Capillary Surfaces

Investigation continued of the quasilinear partial differential equation describing the equilibrium free surface of a liquid partially filling a cylindrical container, subject to the boundary condition that the surface meet the container wall with a fixed angle. Additional local existence criteria for smooth domains were established and an existence theorem for symmetric domains proved. Results of the investigation were applied to obtain expressions for the asymptotic liquid film thickness remaining in a draining circular-cylindrical vessel.

Causes of Leukemia

Work continues in documenting the association of leukemia incidence with prior stress on the white-cell-forming system, and in distinguishing between promotion and induction of leukemia by such stress.[1,2] Transfer of stress across the placenta explains the increase of childhood leukemia incidence with maternal age at birth.[3]

Stem-Cell Regulation

The mammalian liver resembles a stem-cell population. Under study are the mechanisms of liver regeneration and the source of the stimulus for regeneration.[4]

Crystallography

The electronic density of a crystal is non-negative. Positivity of the Fejér means provides an easily executed test that a Fourier approximation to a density represents a non-negative function.

Symbolic Algebra

The SAC-1 system[5] for symbolic algebra on a digital computer was implemented and made available for general use. SAC-1 provides the following operations, among others: addition, subtraction, multiplication, division, and substitution upon multivariate polynomials and rational functions with unlimited-precision integer coefficients.

Spline Functions

Work has continued on the approximation of functions by spline functions, such as:

1) Smoothing data with tolerances by use of linear programming[6]

2) Function and first-derivative fitting by modified quintic splines[7]

3) Smoothing and differential analysis of magnetic field and gradient measurement[8]

4) An optimal cubic spline.[9]

Analogs and computer programs are being developed for numerical solution of second-order ordinary differential equations with initial conditions, by means of cubic splines.

PDP-8/I Time-Sharing

The time-sharing monitor[10] was extended to include log-in and log-out procedures and protected files. An interpretive and interactive debugging routine was completed and is in use. Routines have been written to copy files to and from the magnetic tape unit. A prototype string-oriented editor and a prototype information retreival program have been completed and are operational under the time-sharing monitor.

Technical Text Entry and Editing

Data structures were designed and procedures were implemented for the entry and editing of technical text at a computer terminal that consists of a specially designed keyboard and a storage CRT scope connected to a small computer with disc memory. Characters are software-generated on the CRT as they are entered at the keyboard. The system is designed to allow insertion of additional material into an existing test string, and to provide an on-line proofreading facility with concurrent correction of errors. Software-generated characters are now available for more than 160 different characters, including Latin and Greek alphabets in upper and lower case. All of the characters can be coded as superscript, subscript, italic, boldface, or any combination of these.

A description of this system, including a 10-minute movie, was presented at the 1970 Annual Conference of the IEEE Computer Group.[11] The terminal has been used by Physics Group A and by the Technical Information Division to prepare text for use in LRL publications.

1. PDSR, UCRL-19415, Dec. 1969, p. 104.
2. G. Nooney, Leukopoietic Stress and Leukemia, UCRL-18888, May 1969.
3. G. Nooney, Pregnancy and Leukemia, UCRL-19716, March 1970.
4. G. Nooney, Synthesis and Generalization in Biology, National Meeting of the Society for Industrial and Applied Mathematics, Denver, 1970.
5. F. C. Gey, A User's Introduction to SAC-1, UCID-3447.
6. Jonathan D. Young, Smoothing Data with Tolerances by Use of Linear Programming, UCRL-19403, Nov. 1969 (submitted to Computer Journal).
7. Jonathan D. Young, Function and First Derivative Fitting by Modified Quintic Splines, pp. 33-39, The Logistics Review, Vol. 6, No. 27.
8. Jonathan D. Young, Smoothing and Differential Analysis of Magnetic Field and Gradient Measurement, UCRL-19436, Dec. 1969 (accepted for publication by Particle Accelerator).
9. Jonathan D. Young, An Optimal Cubic Spline, UCRL-19763, April 1970, (accepted for publication by The Logistics Review).
10. PDSR, UCRL-19415, Dec. 1969, p. 107.
11. Loren P. Meissner, Mansfield L. Clinnick, Robert A. Belshe, Low-Cost Source Data Terminal for Technical Text, UCRL-19390 (in Proceedings of the 1970 IEEE International Computer Group Conference). IEEE, New York, 1970.

V. PUBLICATIONS

1. C. S. Fadley, Core and Valence Electronic States Studied with x-ray Photoelectron Spectroscopy, UCRL-19535, April 1970, pp. IV-38 through 48.

2. Steven J. Sackett, An Algorithm for the Numerical Solution of the Nonlinear Magnetostatic Field Equation in Three-Dimensions, UCID-3435, April 1970.

3. John S. Colonias and Arthuc C. Paul, On-Line Calculation of Beam TRANSPORT Systems to First and Second Order, UCRL-19414, April 1970.

4. Elon R. Close, SOTRM: A Program to Generate First and Second Order Matrix Elements by Tracking Charged Particles in a Specified Magnetic Field, UCRL-19823, May 1970.
5. Elon R. Close, Generation of First and Second Order Transformation Elements from a Given Magnetic Field, UCRL-19812, April 1970.
6. Elon R. Close, Generalized Runge-Kutta Schemes: A Global Approach to their Parameter Defining Equations, UCRL-19422, Nov. 1969.
7. Elon R. Close, An Extended Set of Fortran Input/output Routines, UCRL-19463, Feb. 1970.
8. Loren P. Meissner, Mansfield L. Clinnick, and Robert A. Belshe, Low-Cost Source Data Terminal for Technical Text, UCRL-19390, Feb. 1970.
9. Samuel J. Penny, Robert Fink, and Margaret Alston-Garnjost, Design of a Very Large Storage System, UCRL-19757, Rev., June 1970.
10. James Burkhard, Niegel Harrison, and Edward Romascan, The Berkeley Remote Facility (BRF) User's Guide, UCID-3339 (updated through July 1970).
11. G. Nooney, Pregnancy and Leukemia, UCRL-19716, March 1970.
12. G. Nooney, Synthesis and Generalization in Biology, National Meeting of the Society for Industrial and Applied Mathematics, Denver, 1970.
13. F. C. Gey, A User's Introduction to SAC-1, UCID-3447.
14. Jonathan D. Young, Smoothing Data with Tolerances by Use of Linear Programming, UCRL-19403, Nov. 1969 (submitted to Computer Journal).
15. Jonathan D. Young, Function and First Derivative Fitting by Modified Quntic Splines, pp. 33-39, The Logistics Review, Vol. 6, No. 27.
16. Jonathan D. Young, Smoothing and Differential Analysis of Magnetic Field and Gradient Measurement, UCRL-19436, Dec. 1969 (accepted for publication by Particle Accelerator).
17. Jonathan D. Young, An Optimal Cubic Spline, UCRL-19763, April 1970 (accepted for publication by The Logistics Review).
18. Loren P. Meissner, Mansfield L. Clinnick and Robert A. Belshe, Low-Cost Source Data Terminal for Technical Text, UCRL-19390 (in Proceedings of the 1970 IEEE International Computer Group Conference). IEEE, New York, 1970.

DATA HANDLING

Howard S. White in charge

DAPR: FULLY AUTOMATIC SCANNING AND MEASURING OF BUBBLE CHAMBER EVENTS

Howard S. White, Dennis Hall, Joan Franz, Wen-Sue Gee, Barbara Britton

By the end of March 1970, a thorough analysis of the performance of the DAPR system was completed. Film from a 1.53-GeV/c π^+ exposure of the LRL 25-inch hydrogen bubble chamber was selected as representative of an average experiment. Eight contiguous rolls were abstracted. DAPR measurements of 1752 two-prong events were examined and proved to be of the same excellent quality as measurements from the HAZE system. Thus the accuracy of DAPR measurements was firmly established.

The throughput of the DAPR system was observed to be less than that of the HAZE system. Investigation revealed a few, well defined, problem areas: The simple vertex-finding algorithm that was first implemented clearly needed extending; improvement was needed in the ability to follow short tracks; and the art of writing computer scanning criteria was clearly in a primitive state. Work on finding improved procedures in these areas was started.

DAPR was already superior to manual scanning systems in several ways: The full abstraction of all tracks in the picture allowed calibration of ionization and of beam cross section on a frame-by-frame basis. Consistent scanning standards were maintained since the subjective decisions of human scanners were eliminated. Finally, the cost was considerably less than that of manual systems.

Thus, the overall performance of the DAPR system was established and routine production operation was started. At the same time, implementation of improved new techniques continued to upgrade the system.

DAPR has already moved very close to the goal of totally unassisted analysis of bubble-chamber data. Its achievement of this goal seems assured. With human reaction times no longer included in the system, it would be possible with suitable hardware to operate without film, on-line to the bubble chamber. This would allow bubble chambers the same advantages of immediate on-line data analysis which have been so useful in many spark-chamber experiments, while retaining the precision and resolution of the bubble chamber. Only a system which operates without manual assistance can go on-line in this manner. We believe that attainment of operational status by DAPR is a significant step toward these goals.

HAZE: SEMI-AUTOMATIC EVENT MEASUREMENT

Wen-Sue Gee, James Greene, Carol Osborne, Priscilla Davis

The HAZE system of programs continued to operate in routine production status. Although this system is gradually being superseded by DAPR, the major portion of computer time was consumed by HAZE. System improvements were limited to the many small adjust-

ments required to initiate and maintain the processing of new physics experiments.

FCF: GEOMETRY, KINEMATICS, DATA DISPLAY

Loren Shalz, Vivian Morgan, Shirley Buckman, and Michael Block

The FOG, CLOUDY, FAIR system of programs which provide the analysis of bubble-chamber events for the HAZE and DAPR systems continued routine production operations. Many new experiments and event types were set up and processed.

A low-key effort to define standardized library formats was undertaken in collaboration with Group A, Math and Computing, and the Segrè-Chamberlain, Trilling-Goldhaber, and Powell-Birge groups. It was hoped that more communication between bubble-chamber data-processing groups would avoid duplicate effort as well as improve the laboratory's data-processing abilities. To this end the existing FCF library documentation was carefully reviewed, and work was started on obtaining clean assemblies of all FCF programs.

EVENT ACCOUNTING

Shirley Buckman

Routine production of the Event Accounting programs continued. Improvements were limited to the necessary changes required by the DAPR system together with the normal maintenance required by the changing needs of physics experiments.

TRIST: SYSTEM MONITOR

Carol Osborne and Priscilla Davis

A new assembly of the system monitor (TRIST 9) was debugged and put into production operation. The greater demands placed on the hardware and software by the DAPR system required several system improvements. The ability to recover processing summaries after a break-down was added, and restart procedures in general were improved.

In order to distinguish low-frequency computer failures from system program bugs, a more thorough record of machine conditions was provided in the case of apparent program malfunction. This was made necessary by the asynchronous nature of operations in a multiprogrammed environment.

A time-accounting program was also designed and partially written which produces a summary report of all 7094-II Data-Handling operations. This will summarize on a daily basis the distribution of jobs, the amount of lost time, and the efficiency of computer operations. With it, supervisory personnel can be more effective in monitoring performance as well as in planning the next day's work load.

QUARKS

Dennis Hall, Shirley Buckman, and Loren Shalz

In collaboration with the Cloud Chamber Group at Livermore, a computer program was written for Dr. Wilson Powell which will assist in the identification of quark particles. This program inputs two-point measurements of track images from a modified SPV-B image-plane digitizer, and produces a spatial description of the flight path. In addition, the position of the track image relative to known fiducial marks is generated. The output of this program, on magnetic tape, is then shipped to Las Vegas where an accurate measurement of droplet density is taken. It is hoped that in this way the existence of particles of less than unit charge can be established.

A CDC-6600 program, which writes onto the chipstore a permanent record of all data processed, was also written so that final summarization can be easily achieved. A program

which converts the final data-tapes to FAIR-system format was also written. This allows the full power of the FAIR data-summary programs to be employed in the search for an extremely rare phenomenon.

During this time period, 1136 cloud-chamber images were processed, or approximately 2200 tracks.

DATA-PROCESSING OPERATIONS

The following table summarizes the processing of events measured on the COBWEB, HAZE, and DAPR systems. An event is the entire collection of related vertices measured in a bubble-chamber picture. New measurements of the same event are counted separately, but the effect of any computer reprocessing has been eliminated from the totals.

EVENT MEASUREMENTS ANALYZED

Experiment	Chamber	Beam	Group	Number of events
COBWEB system				
45	25" HBC-LRL	1.53-1.84 GeV/c π^+p	Powell-Birge	346
46	25" HBC-LRL	1.53-1.84 GeV/c π^+p	Powell-Birge	5 394
47	25" HBC-LRL	1.53-1.84 GeV/c π^+p	Powell-Birge	1 028
50	25" HBC-LRL	1.16-1.57 GeV/c K^-	Powell-Birge	7 691
51	25" HBC-LRL	1.16-1.57 GeV/c K^-	Powell-Birge	18 827
52	25" HBC-LRL	1.16-1.57 GeV/c K^-	Powell-Birge	28 146
		Total COBWEB measurements processed		61 432
HAZE system				
01	82" DBC-SLAC	12.0 GeV/c π^-	U.C. Riverside	60 069
45	25" HBC-LRL	1.53-1.84 GeV/c π^+p	Powell-Birge	32 157
46	25" HBC-LRL	1.53-1.84 GeV/c π^+p	Powell-Birge	2 036
53	25" HBC-LRL	1.16-1.57 GeV/c π^+p	Powell-Birge	35 078
54	25" HBC-LRL	1.16-1.57 GeV/c π^+p	Powell-Birge	15 590
71	72" DBC-LRL	6.0 GeV/c p	Segrè-Chamberlain	297
72	80" DBC-BNL	8.0 GeV/c p	Segrè-Chamberlain	22
91	72" HBC-LRL	3.5 GeV/c π^+	Trilling-Goldhaber	1 139
95	82" DBC-SLAC	12.0 GeV/c K^+	Trilling-Goldhaber	126 853
		Total HAZE measurements processed		273 241
DAPR system				
57	25" HBC	1.56 GeV/c π^+p	Powell-Birge	52 435
		Total events analyzed		387 108

Accelerator Operation and Development

ACCELERATOR STUDY GROUP

Edward J. Lofgren in charge

ELECTRON RING ACCELERATOR STUDIES

In the 8-month period ending 30 June 1970, the Electron Ring group finished and analyzed the Compressor-3 experiment in Livermore, partially completed a new 2.25-MeV electron accelerator and electron-ring facility in Berkeley, prepared and planned further compressor and ion-acceleration experiments, and completed a feasibility study of an electron-ring accelerator for accelerating protons to high energy.

Compressor-3 Experiment

The principal goal of the Compressor-3 experiment was to demonstrate the acceleration of positive ions by electron rings. The experiment was carried out at the Astron facility in Livermore in two 3-week periods, one in August for equipment check-out and preliminary experiments and a final period in November-December. The primary purpose of the experiment (collective acceleration of ions) was frustrated by the failure of the preliminary steps of forming and compressing rings of adequate intensity and quality--steps that had been successfully accomplished a year earlier in the Compressor-2 experiment. The rings at full compression were down in intensity by a factor of 4 to 10, and larger in both minor dimensions by a factor of 2 or 3, relative to those of Compressor 2. As a result, the rings had insufficient holding power and inadequate self-focusing. The extraction system designed for moving and launching the electron rings performed properly both electrically and dynamically, and the electrons were accelerated axially. However, because of the poor quality of the rings, the electrons were accelerated individually rather than as integral, focused rings.

The difficulties with formation and compression of the electron rings occurred early in the compression cycle. At high levels of injected beam from the 3.5-MeV Astron accelerator, the rings very quickly spread radially and shifted lower in average energy. This effect occurred within 100 nsec. As the beam level was decreased, this spreading effect went away. These symptoms were suggestive of the negative-mass effect, in which the electrons tend to clump azimuthally like the beads of a necklace. Since this effect can be suppressed by the smearing effect (Landau damping) due to a spread in electron energies, the instantaneous energy spread of the beam from the Astron accelerator was measured, using the compressor as an analyzer, and found to be no more than 0.1%. The Astron accelerator had been completely rebuilt between the Compressor-2 and Compressor-3 experiments. During Compressor 2 the same measurement had shown a 0.5% energy spread in the beam from the previous version of the Astron accelerator. Since the threshold for the negative-mass effect is proportional to the square of the instantaneous momentum spread, these measurements indicated a smaller threshold by a factor fo 25 or more for the Compressor-3 situation. The final energy spread in the electron ring (about 10% for a ring of

4×10^{12} electrons) also was consistent with this negative-mass interpretation.

A second major difficulty in the compression cycle occurred even at low intensity. Within about 30 μsec of injection (the exact time depending upon the details of the magnetic cycle being used), the beam expanded axially, and most of it was lost to the side walls of the vacuum chamber. Analysis after the experiment has adequately explained these effects as due to single-particle resonances. Such electron-orbit resonances can occur when the radial and axial betatron tunes ν_r and ν_z are integrally related, as $a\nu_r + b\nu_z = c$, where a, b, and c are small integers related to the shape of the magnetic perturbation that can drive the resonance. The occurrence of these resonances can be controlled by the magnetic cycle of compression, because the betatron tunes are related to the magnetic index n (the normalized radial gradient of the magnetic field) as: $\nu_r^2 = 1 - n$, and $\nu_z^2 = n$. Detailed single-particle orbits were followed using a computer code in which the measured magnetic fields of Compressor 3 were included. These calculations showed in the normal compression cycle that the resonance $\nu_r - \nu_z = 0$ could cause a disastrous axial blow-up. This resonance occurs when $n = \frac{1}{2}$. Other compression cycles were tried during the experiment, in which n was kept below $\frac{1}{2}$ throughout the cycle, but in these cases, the calculations showed that other resonances at $n = 9/25$ ($\nu_r + 2\nu_z = 2$) or at $n = 1/4$ ($2\nu_z = 1$) resulted in excessive blow-up when driven by the measured magnetic perturbations.

Compressor 2 initially had similar difficulties with single-particle resonances, but an n-trajectory during the compression cycle was devised in which the crossing of the bad resonances was delayed until a small radius where the magnetic perturbations were relatively small. In the design of Compressor 3 the magnetic design was modified so as to avoid crossing the $n = 9/25$ and $n = 1/4$ resonances until as small a radius as possible. However, this change inadvertently made the $n = \frac{1}{2}$ resonance, which had been relatively benign in Compressor 2, much more severe in Compressor 3 and was a principal source of our resonance difficulties.

New Injector Facility in Berkeley

The difficulties with Compressor 3 have emphasized the utility of a new electron facility at which complicated experimental systems can be carefully and systematically explored and deliberately modified as needed.

Such a facility has been under construction at LRL-Berkeley since last fall. The facility consists of a 2.25-MeV linear induction accelerator capable of producing short, intense bursts of electrons, plus an experimental area for electron-ring research.

The design of the accelerator is a refreshingly new one, and many of its features are novel. The accelerator is modular, consisting of 17 linear induction cavities, each capable of producing 250 kV with a beam load of 1000 A. Each cavity is fed by a 40-nsec pulse produced by an oil-filled Blumlein pulse-forming line, which in turn is charged by a Marx generator. The induction cores in the cavity are made of blocks of ferrite epoxyed together. The synchronized switching of these components is done by means of pressurized, triggered spark gaps. Relative jitter times between the pulses applied to a group of cavities is on the order of 1 nsec or less. All of these components were recently developed and built at LRL. This type of accelerating structure, in addition to being useful in forming an injection accelerator, is probably the best type for a high-energy electron-ring accelerator for protons. As a result, some design parameters were stretched so that these

cavities could serve also as a developmental model for such eventual usage.

This accelerator design has proved to be relatively inexpensive. In spite of its developmental nature, the cost of the accelerator structure (exclusive of building) is only about 200 k$ per MeV.

The electron gun, shown in Fig. 1, consists of 5 of these cavities stacked together and coupled by an axial metal rod extending down to the fifth gap. The voltage on the end of this rod thus is the sum of the voltages of the first five cavites, or about 1.25 MeV. The cathode at the tip of the rod is a cold-cathode, field-emission type. This geometry is compatible also with a thermionic-emission type

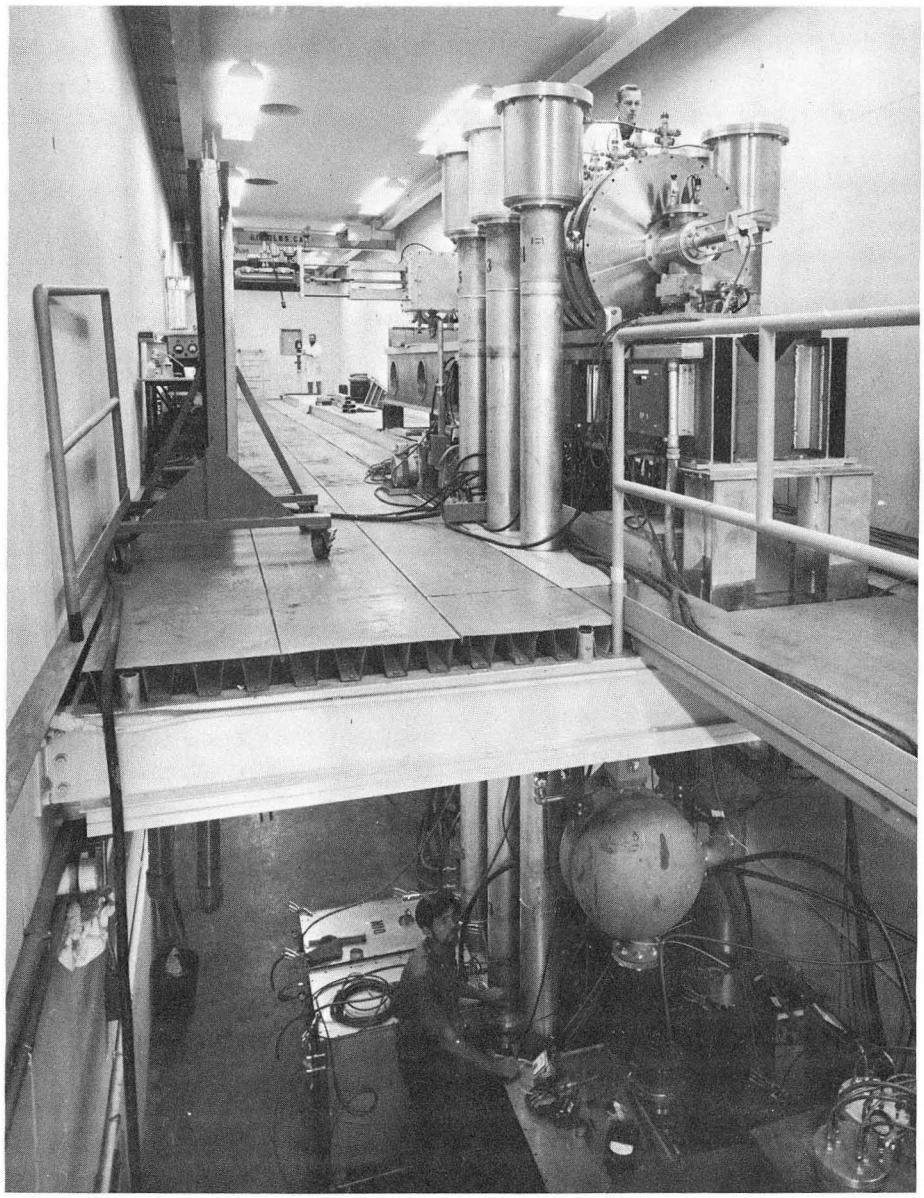

Figure 1

of cathode, but because of their relative simplicity, so far only field-emission types have been tried.

The 5-cavity electron-gun assembly was first operated in May and immediately produced over 1000 A at about 1.2 MeV. Various cathode materials and geometries are being explored. Needle geometries were tried first and gave adequate intensity but generally were unsatisfactory with respect to lifetime. A spiral cathode, consisting of the edge of a metal ribbon wound in a loose spiral, has recently looked better in this regard. Beam-emittance measurements thus far have been preliminary; but if true, the indicated beam brightness is suitable for electron-ring research.

The components for the next 1-MeV increment in beam energy are complete and ready for final installation.

Further Electron-Ring Experiments

Two new electron-ring experiments are being prepared. The first, called Compressor 4, is a limited effort, directed only at the investigation of beam dynamics during the early part of the compression cycle. Single-particle resonances and negative-mass effects are the primary things to be explored, partly to confirm our analysis of the difficulties of Compressor 3. Injection-trapping mechanisms will also be examined if time allows.

Compressor 4 will be set up inside the accelerator shielding enclosure, and will use the 2-MeV beam beginning in August or September. The instantaneous energy spread in the beam will be an important experimental parameter and will be provided by a tapered beryllium foil.

The second experiment being prepared is directed toward the acceleration of ions by electron rings. It will be quite similar to Compressor 3, modified, of course, to avoid its pitfalls. It will be set up in the new experimental area beginning in October or November; experimentation should begin soon after.

Feasibility Study of a High-Energy Electron-Ring Accelerator for Protons

A detailed study of a 80- to 100-GeV electron-ring accelerator for protons was made to reassess the feasibility of such a concept. The accelerator consists of (a) a compressor, in which the electron rings are formed, compressed, and loaded with protons, (b) a 320-m column for electric acceleration, in which the rings are accelerated by the electric field of pulsed cavities up to about 40 to 50 GeV, and (c) a 160-m column for magnetic acceleration, in which a slightly tapered field from a superconducting solenoid raises the proton energy to 80 to 100 GeV.

In this study the parameters allowed for the electron rings and for the machine components were constrained to maintain ring stability against negative-mass and other dynamic effects throughout the machine and also to be realistic from an engineering point of view.

The outcome of the study was that such high-energy accelerators do indeed appear to be feasible and that their cost would be on the order of 350 k$ per GeV, which is considerably less than for a conventional synchrotron.

SUPERCONDUCTIVITY

Dipole Transport Magnets

The construction of a large bending magnet (6.5-in. i.d., length 3 ft, central field 35 kG) was begun when multicore NbTi composite conductor was available only in the untwisted configuration. The 6 inner layers were wound from the untwisted conductor and the outer 2 layers from a twisted conductor. The magnet was badly degraded due to instabilities in the

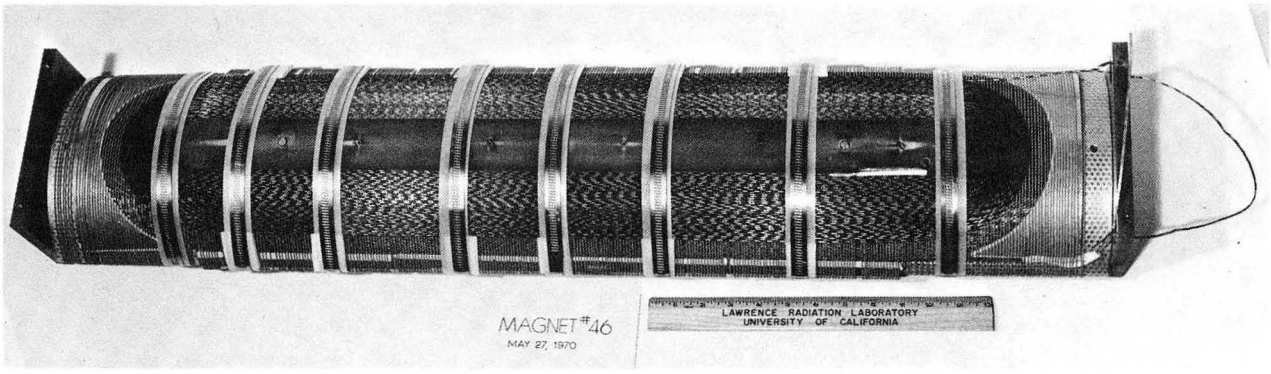

Figure 2

untwisted material, and a central field of only 20 kG was obtained. The outer 2 layers, when separately energized, were degraded through close coupling with the unstable material underneath. The outer 2 layers were then placed by themselves on a different bore tube and the transition current increased from 740 A to 1170 A. We decided not to use this magnet on a Bevatron beam since the field achieved was so degraded.

A larger bending magnet using twisted multicore NbTi composite conductor is under construction. The magnet will be housed in a horizontal warm bore Dewar for use in Bevatron beam lines. The warm bore is 8 in. in diameter, the central dipole field is to be 40 kG, the physical length is 40 in. An outer magnetic shield of iron will surround the Dewar.

Quadrupole Transport Magnets

A focusing doublet for Bevatron use with two quadrupoles in the same cryostat has been begun. The design specifications for each quadrupole are: 8 in. warm bore, 27 in. effective length, 34 in. physical length, gradient of 6 kG in.$^{-1}$

Two full-size practice layers, for one quadrant, have been built and tested (Fig. 2). The transition current for 1 layer is 1550 A and for 2 layers is 1210 A; the 8-layer-thick winding requires 850 A to reach the design gradient.

Accelerator-Type Pulsed Dipole

The first in a series of pulsed dipoles using intrinsically stable multifilament NbTi composite conductor has been built and tested. The dipole has 4 in. i.d., 6 in. o.d., 16 in. length, and contains some 25 lb of conductor. Without any iron return yoke the central dipole field would be 40 kG if the magnet reached the short-sample capability of the superconductor. The twisted composite conductor is 0.040 in. in diameter, has 355 NbTi filaments each 1.2 mils (30μ) in diameter.

The dipole was made in two halves, one of which has internal electrical shorts due to failures in the Formvar insulation (Fig. 3).

Initial tests were made before the windings were wax-impregnated; some helium permeation was possible. Loud mechanical clicking was heard during magnet charging. We associate these noises with wire movement under

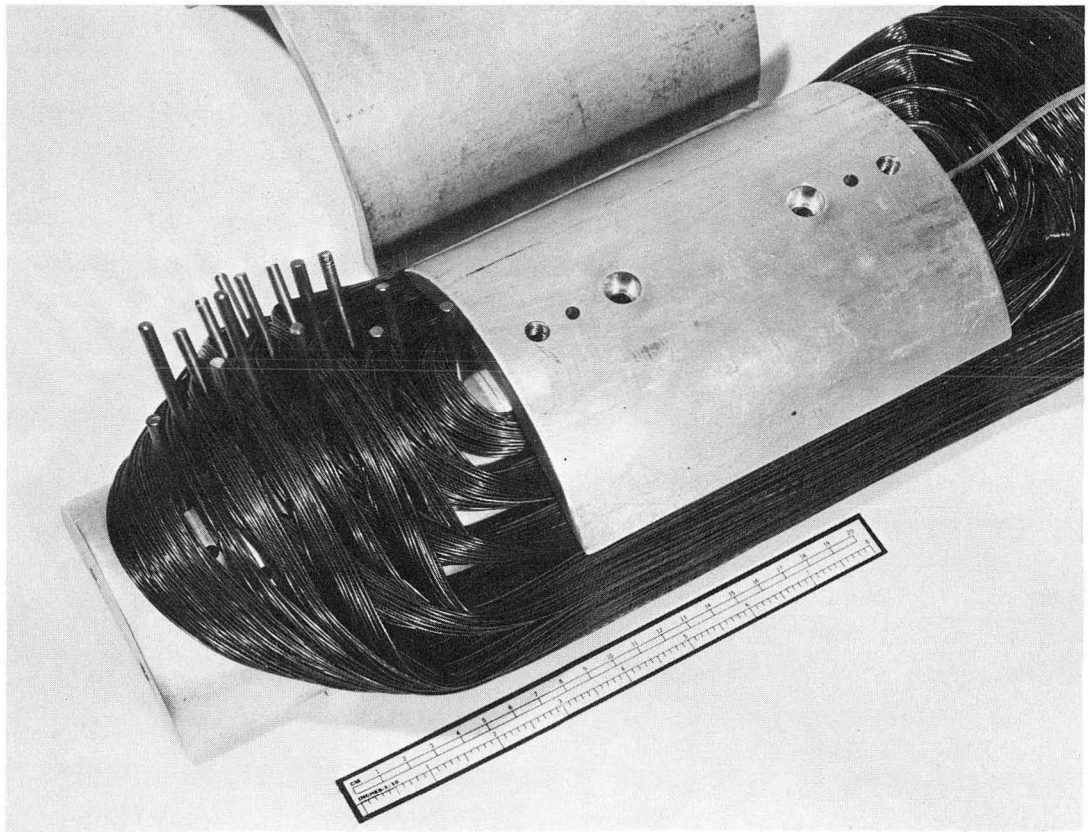

Figure 3

magnetic forces. The transition currents under slow charging were some 220 A in each half of the dipole, corresponding to some 23 kG at the wire in the end windings. With both halves energized, the forces are greater and the entire magnet transitioned at 160 A or some 19 kG in the bore (some 20 kG in the ends). Pulsed losses were measured but were abnormally high due to the shorts in the defective half.

The entire magnet was wax-impregnated to reduce wire movement and cooling was effectively reduced to end cooling only. The transition currents in the two halves, tested separately, were unchanged. For the entire magnet, however, the transition current increased to 196 A (24 kG central field, 25 kG end winding). Subsequent inspection of the magnet showed appreciable wire displacement.

Initial pulsed tests of the good half show expected losses of some 5 J per cycle, or $Q > 50$.

Fundamental Studies — Magnet Degradation and Pulsed Losses

We built 12 test solenoids containg some 2 kg of conductor with dimensions of: 2 to 2-3/8 in. i.d., 2-3/8 in. length, and 4 to 5 in. o. d. The maximum field in the conductors ranged from 25 to 55 kG depending on the material and the amount of magnet degradation. The magnets were tested for transition current as a function of charge rate, and cyclic loss rate under pulsed operation. The twisted multicore conductors generally performed close to their short-sample capabilities; magnetization studies of these conductors showed them to be stable against flux jumps

up to 5 kG/sec sweep rates. The untwisted multicore conductors gave badly degraded performance; their magnetization loops displayed flux jump instabilities at rates of change as low as 100 G/sec.

One solenoid uses 49-wire cable in which each multifilament wire is 0.009 in. in diameter and each filament is 0.4 mil (10μ) in diameter. This magnet was degraded some 20% due to wire motion. Short-sample behavior was achieved when the magnet was impregnated with paraffin wax. The pulsed losses were as low as expected but relatively little heat could be removed through the wax. The magnet goes normal when the heat generation is about 1 W (40 kG maximum field).

Fundamental Studies – Superconductor Resistivity

We have been measuring the critical-current characteristics of small-diameter multicore wires, and consequently have been improving the sensitivity of our short-sample measuring facility. The apparatus is now equipped with an automatic current turn-off to prevent burning out samples. The critical current at a given field for 8-mil-diameter wires was found to vary with the sensitivity of the automatic current turn-off feature. We formerly tested 2-in. samples of material, but in the new apparatus we have been testing 54-in. samples which are bifilar wound. Because of the long length and small cross section of the samples we are able to measure the resistivity of the superconducting samples down to about 2×10^{-14} ohm-cm. The resistivity of the multicore wires is a nonlinear function of both magnetic field and current density, and it varies by a factor of about 1000 from the threshold of sensitivity to the point where it becomes unstable and goes normal. The slope of logarithm of resistivity vs logarithm of current density does not vary rapidly with field or current density in a given sample, but does vary with different samples. One sample which has many broken strands shows a typical value of $\log \rho / \log J \approx 2$, but other samples which have very few if any broken strands have typical values of $\log \rho / \log J \approx 6$. Twenty samples of different superconductors have been measured.

PUBLICATIONS AND PAPERS

1. C. Pellegrini and A. Sessler, Lower Bounds on Ring Self-Focusing so as to Maintain Ring Integrity During Spillout and Subsequent Acceleration, Nucl. Instr. Methods, 86, 273 (1970).

2. D. Keefe, Research on the Electron Ring Accelerator, Particle Accelerators I, 1(1970).

3. C. Pellegrini, Synchrotron Formation and Ring Formation in the Electron Ring Accelerator (UCRL-19815, May 1970), presented at 2nd Natl. Conf. Particle Accelerators, Moscow, USSR, Nov. 1970.

4. R. Hazeltine, M. Rosenbluth, A. Sessler, Diffraction Radiation by a Line Charge Moving Past a Comb: A Model of Radiation Losses in an Electron Ring (UCRL-19793, April 1970), to be published J. Math. Phys.

5. D. Keefe, Electron Ring Accelerators, presented at Gordon Conf. Plasma Physics Issaquah, Washington, June 1970.

6. Michael A. Green, Refrigeration of Superconducting Magnets (UCRL-19758, April 1970), submitted to Particle Accelerators.

7. W. S. Gilbert and R. B. Meuser, Superconductivity for High Energy Physics at LRL-Berkeley (UCRL-19769, April 1970), submitted to Particle Accelerators.

8. Robert C. Acker and Ferd Voelker, Experimental Superconducting Transformer for Current Step-up (UCRL-19762, April 1970), submitted to Particle Accelerators and presented at 1970 Applied Superconductivity Conference, Boulder, Colorado, (June 15-17, 1970).

9. Ferd Voelker, Resistance in Small, Twisted, Multi-core Superconducting Wire (UCRL-19761, April 1970), submitted to Particle Accelerators.

BEVATRON

Edward J. Lofgren in charge

BEVATRON OPERATION

During the period covered by this report, the Bevatron provided beam for 28 primary experiments and 7 secondary experiments, a total of 35 experiments. Thirteen primary experiments and 2 secondary experiments were completed. The machine ran 85% of the scheduled operating time. This amounted to 3,319 hours of beam for the research program and an integrated total of 13,358 hours of experimentation. Thus the average multiplicity was 4.0. A total of 7.1×10^{18} protons were accelerated during this time.

The Bevatron was shut down on November 27, 1969, and remained shut down until January 6, 1970. The length of the shutdown was unusually long and was related to budgetary cutbacks during the fiscal year. The timing of the shutdown was chosen to coincide with the holiday season in order to minimize the number of interruptions to the experimental program. The principal job carried out during the shutdown was the installation of the new septum beam line of the External Proton Beam Channel I. Work on the septum split continued through January. Advantage was taken of this shutdown opportunity to do a thorough inspection of the main motor-generator sets and to perform routine quarterly maintenance.

Bevatron operation resumed on January 6, 1970, for internal target experiments only. On January 20, work on the septum split had progressed far enough to permit operation in Channel II of the EPB system. By the end of February, the septum beam split had been checked out and placed in operation. By March, Bevatron operation had returned to normal with good beam and an average of 3.5 experiments operational.

There was a 3-day shutdown in April for quarterly maintenance of the main motor-generator sets. Modification and installation of diagnostic equipment for beam studies were made inside the Bevatron vacuum chamber during this shutdown.

The 25-in. hydrogen bubble chamber took its final pictures on the 25th of May. The chamber and associated equipment have been dismantled since that date. The phasing out of bubble-chamber operations was one of the means taken by the Laboratory to meet next year's reduced budget.

On the 12th of May, we discovered a small water leak into the main Bevatron vacuum tank from the water circuits of "M1" septum magnet, the first magnet in the EPB extraction system. The Bevatron was let to air to inspect the leak and to determine the feasibility of making repairs. The leak was at an epoxy glued joint on a water manifold. Attempts to seal the leak failed. Because of the high level of residual radiation in the area and the inaccessibility of the leak, we decided to remove the magnet and attempt repairs outside the main Bevatron tank where access would be better. After removal of the magnet and a closer inspection, we decided repair was

impracticable. Therefore the magnet was replaced by an older version that had previously been used. This magnet had a 0.5-in. septum rather than the 0.130-in. septum of the newer model. The expedient of using the older magnet will result in a temporary reduction in extraction efficiency of about 20%. The septum magnet mounting was reworked to allow retention of quadrupole magnet (Q1) on the same plunging mechanism. Work was completed by the 17th of May.

Fabrication of a new thin septum (0.130-in.) magnet was undertaken and should be ready to install in the fall of 1970. Construction of a spare M1 magnet had been delayed in order to take advantage of development work in progress related to resonant extraction.

We resumed good operation during June and operated for an average of 4.5 experiments.

BEVATRON STUDIES

Machine studies continued this period with the bulk of the time devoted to resonant-extraction studies and an investigation of vertical beam blow-up during flattop when the rf voltage is turned off. The failure and subsequent replacement of the M1 septum magnet slowed down some phases of resonant-extraction study. The major effort was then devoted to study of the vertical blow-up of the beam with the rf voltage off. Control of the vertical growth is necessary if we are to gain maximum improvements from an operational resonant-extraction system. Improvements continued in computer control of the EPB magnets and the main Bevatron magnet pulsing modes. Some effort was devoted to beam structure studies.

184-INCH CYCLOTRON

James T. Vale in charge

The 184-in. cyclotron was used for research experiments approximately 86.6% of the time that the operating crew was on duty. The innage was low this period because of the overhaul of the large generators that power the main magnet.

The large generators are operated almost continuously, and thus accumulate large amounts of carbon dust throughout their interstices. This dust comes from the normal wear of the carbon brushes rubbing against the commutators. When the leakage resistance to ground gets to a certain point the generators have to be essentially dismantled and washed with solvents. This has to be done approximately every 5 years.

MAJOR EXPERIMENTS CONCLUDED

Muon Capture γ Rays	Moyer - Kaplan
π^0 Form Factor	Moyer - V. Perez-Mendez
Magnetic Moment of μ^-	Williams — Univ. of Wash.
$\pi^- + p \rightarrow n + \gamma$	Haddock — UCLA
Biomedical Effects of π^- Patient Treatment	(continued) John Lawrence

SETUPS FOR NEW EXPERIMENTS

$p + d \rightarrow {}^3He + \gamma$	Moyer - V. Perez-Mendez
$\pi^- + A \rightarrow 2p + A'$	Macek — LASL
$n^+p \rightarrow d + Y$	Young, Longo — Univ. of Wash. Univ. of Mich.

ACCOMPLISHMENTS

1) High-power second dee under construction.

2) Engineering studies have continued on 184-in. improvement program.

3) Additional beam transport magnets have been received.

4) Much shielding has been acquired, and additional shielding is being ordered.

5) The large generators for the main magnet have been overhauled.

6) The beam intensity has been increased (30-40%) this fiscal year by means of dee bias pulsing.

Appendix

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