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May through October 1969

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PHYSICS
Semiannual Report

May through October 1969

December 1969

David L. Judd
Associate Director for Physics

LAWRENCE RADIATION LABORATORY
University of California
Berkeley, California

PHYSICS SEMIANNUAL REPORT

May through October 1969

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ABSTRACT

Theoretical Physics: Chew

Strong Interactions: multiperipheral dynamics, Regge trajectories, multiparticle processes, charge-exchange scattering, elastic scattering, spectral functions, quarks, Veneziano model, dual Feynman theory, relativistic wave equations, Dirac matrices, S-matrix theory, Lorentz symmetry, Clebsch-Gordan coefficients, current algebra, sum rules.

Weak and Electromagnetic Interactions: weak radiative decay, S-matrix formulation, pseudoscalar coupling, Veneziano parameterization, photon mass.

Plasma and Atomic Physics: excitation, collision, Green's function, fully ionized gas, electron scatterings plasma instability, turbulent plasma.

Statistical and Many-Body Physics: superfluid helium, ionic crystals, density matrix, statistical thermodynamics.

Accelerator Theory: electron ring accelerator, image-field coefficients, oscillations in plasma, thin-lens optics, particle acceleration.

Experimental Physics

Group A: Solmitz

Bubble Chamber Experiments: associated production, K63 experiment (K^- on H and on D, 1.7 to 2.73 GeV/c), K65 (K^- on H, 400 MeV/c), π66 (π^+ on D, 1.1 to 4.2 GeV/c, BP66 (p on H, 13 to 28.5 GeV/c), P65 (p on H, 5.5 and 6.6 GeV/c), LRL-SLAC on inelastic reactions, K82 (K^+ on p, 12 GeV/c, 35 events/μb), π82 (π^+ on H, 7 GeV/c), backscattered laser beam.

Accelerator Experiments Using Spark Chambers: with Moyer-Helmholz: η neutral decay, search for $N^*(1680) \rightarrow n\eta$, neutral dibosons; deuteron missing mass.

Experimentation Using Cosmic Rays: spectra up to 120 000 miles, emulsion spectrograph, cosmic ray muons.

Search for Monopoles.

Detectors Using Liquefied Noble Gas.

Data Reduction Operations: effort, scanning, measuring.

Programming Effort: bubble chambers, spark chambers, general support.

Particle Data Group: particle properties, particle cross sections, systems development.

Crowe-Miller

Magnetic moment of muon, S-wave π-π interaction, differential σ for $\pi^- p \rightarrow n\gamma$, radiative capture of π^- mesons.

Heckman

Inner-belt protons, identifying trapped particles, rigidity spectra of heavy cosmic-ray ions.

Lofgren

Diboson production by pions, branching ratio $(K^+ \rightarrow e^+ \nu)/(K^+ \rightarrow \mu^+ \nu)$, neutral leptonic currents.

Moyer-Helmholz

Neutral decay mode of K_L^0, $K^+ \rightarrow \pi^+\pi^-e^+\nu$, pion lifetimes, η^0 decay and $\pi^0\pi^0n$ experiments, μ^- capture γ rays, time-reversal invariance, $\pi^- + {}^3He$ interactions, π^0 form factor, photoproduction of vector mesons, wire chambers, streamer chamber.

Powell-Birge

$\pi^+ + p \rightarrow K^+ + \Sigma^+$, resonances in π^+p interactions, K^-p exposures, K^-d and K^-n elastic scattering, two-prong events in π^+p film, data reduction.

Segrè-Chamberlain

p-d interactions, π^--p interactions, p-p interactions, T violation in hadron interactions, polarization in elastic ep scattering, asymmetry in photoproduction of π^+ from polarized p, polarization in backward np scattering, search for $K^+ \rightarrow \pi^+ + \nu + \bar{\nu}$, kaonic atom x rays.

Atomic Beam Group: Shugart

Atomic and molecular beams, optical and electron pumping, atomic Stark effect, metastable electronic states, Lamb shift, find structure in ${}^3He$, resonances in H_2, spins and moments of Ge and Tm isotopes, atomic decays, free radical, mass-spectrometer detector.

Trilling-Goldhaber

K^+p interactions, K^+d interactions, π^+p interactions, ionization measurement by the FSD, K^+p elastic scattering, Λp and Λd interactions, $\bar{K}N$ interactions and K_{e3}^0 decay.

Van Atta

High-frequency oscillations in beam-plasma system, high-current sheet pinch plasma and laser beam photon scattering, microwave-generated plasma source, injection and trapping of laser-produced plasma, plasma transport across magnetic fields, high-temperature plasmas, computer simulation of plasma behavior, kinetic equations for particles and waves.

25-Inch Hydrogen Bubble Chamber: Powell-Kadyk-Eckman

Gas purity, camera operation and improvements, operating conditions, internal targets, film production totals.

Health Physics: Patterson

Environmental radiation, radioactivity produced in accelerator shielding, γ and n spectroscopy and shielding problems, ERA monitoring and shielding, Bevatron monitoring, neutron activation analysis for monitoring, spark chamber applications, exposure estimates from ${}^{11}C$ activity, laser safety, neutron spectra quality factor.

Computing and Data Handling

Applications Programming

For physics research, for nuclear chemistry, for accelerator and magnet design, for biomedical applications, for Bevatron beam control, data acquisition, typesetting, shop applications, printed circuits, and information processing.

Systems Programming

ASOP, MSS and PSS, BRF, RECC, computer acquisition.

Computer Operations

Revisions of layout, new equipment and procedures.

Research in Mathematics and Computer Science

Geometric problems, spline functions, biological problems, crystallography, text entry station.

Data Handling

Development of new systems for automatic scanning and measurement, maintenance of existing system, data-processing operations totals.

Accelerator Operation and Development

Accelerator Study Group

Superconductivity, construction and testing of Compressor III, electron injector.

Bevatron

Computer control of pulse modes, resonant extraction of EPB, septum EPB channel, "growth" of beam before extraction.

184-Inch Cyclotron

Experiments performed, beam-transport magnets, shielded platforms, intensity-increase studies, second dee system

Physics Research Staff

Physics Research

THEORETICAL PHYSICS

Geoffrey F. Chew in charge

I. PHYSICS OF STRONG INTERACTIONS

MULTIPERIPHERAL DYNAMICS WITH PION DOMINANCE

Geoffrey F. Chew, Terence W. Rogers,*† and Dale R. Snider

The original (1962) ABFST multiperipheral model[1] is being used to illuminate certain obscure aspects of the (1968) CP multi-Regge model.[2] The kernel of the ABFST integral equation is proportional to the elastic $\pi\pi$ cross section, and it has been shown that the smallness of the CP Pomeranchuk coupling--a central feature of that model--is "explained" by the smallness of the high energy $\pi\pi$ elastic cross sections. The ABFST kernel is dominated by low energy $\pi\pi$ resonances, which can be associated with the "meson trajectory" in the CP model. A surprising development has been that the $J = 0$ pion link in the ABFST model, because of the very small pion mass, behaves like a trajectory with intercept at $J = 1/2$ in the CP model. In the realistic description of high energy collisions the ABFST model is qualitatively promising, but quantitative applications are obstructed by a serious off-shell ambiguity.

*Miller Postdoctoral Fellow.
†Present address: Cavendish Laboratory, Cambridge, England.

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); L. Bertocci, E. Predazzi, A. Stanghellini, and M. Tonin, Nuovo Cimento 27, 913 (1963).
2. G. F. Chew and A. Pignotti, Phys. Rev. 176, 2112 (1968).

DIAGONALIZATION OF THE MULTIPERIPHERAL EQUATION AT GENERAL MOMENTUM TRANSFER

Marcello Ciafaloni,* Carleton DeTar, and Michael N. Misheloff

Making use of the full O(2, 1) symmetry of the Chew-Goldberger-Low multiperipheral equation,[1] we have achieved a partial diagonalization of the equation for general momentum transfers. The method has been applied to two specific models for multiparticle production amplitudes--an AFS-type model and a leading term multi-Regge model. This work has been completed.[2]

*On leave of absence from Scuola Normale Superiore, Pisa, Italy, and INFN, Sezione di Pisa, Italy.

1. G. F. Chew, M. L. Goldberger, and F. Low, Phys. Rev. Letters 22, 208 (1969).
2. Marcello Ciafaloni, Carleton DeTar, and Michael N. Misheloff, Multiperipheral Dynamics at General Momentum Transfer (UCRL-19286, Aug. 1969), Phys. Rev. (to be published).

O(2, 1) SYMMETRY OF THE MULTIPERIPHERAL EQUATION AT ZERO MOMENTUM TRANSFER

Marcello Ciafaloni* and Carleton DeTar

We study the limit $t \to 0$ of the multiperipheral equation in the equal-mass case after diagonalization with respect to the O(2,1) group, and relate solutions to the equation so obtained to solutions that result from the application of the full O(3, 1) symmetry.[1] We obtain the expected sequence of daughter poles for each O(3, 1) pole. We also simplify the O(2, 1) diagonalization of the multiperipheral equation in the BCP model[2] and the O(3, 1) diagonaliza-

tion obtained by Mueller and Muzinich.

---

*On leave of absence from Scuola Normale Superiore, Pisa, Italy, and INFN, Sezione di Pisa, Italy.

1. A. H. Mueller and I. J. Muzinich, Diagonalization of the Integral Equation for Multiperipheral Dynamics at Vanishing Values of the Momentum Transfer, Brookhaven Report 13728, May 1969.
2. A. H. Mueller and I. J. Muzinich, Multiperipheral Dynamics at Nonvanishing Values of Momentum Transfer, Brookhaven Report 13836, June 1969.

STUDY OF THE RELATIONSHIP BETWEEN THE MULTIPERIPHERAL MODEL AND THE STRIP MODEL

Carleton DeTar

The unitarity expression for the absorptive part of a two-body scattering amplitude in terms of integrals over multiparticle production amplitudes may be continued in momentum transfer. If the production amplitudes are expressed according to the multiperipheral model, the double spectral function for the two-body amplitude, calculated by taking discontinuities of the unitarity expression in momentum transfer, strongly resembles the double spectral function obtained from a Mandelstam iteration in the strip model. This method provides a route for comparing the merits and deficiencies of the two models.

ON SOME PREDICTIONS OF THE AFS MULTIPERIPHERAL MODEL

Don M. Tow

The AFS multiperipheral model[1] with pion-pole dominance predicts some features for high energy scattering that are in qualitative agreement with experiment. The model predicts Regge asymptotic behavior, average multiplicity growing like $\ln s$, a constant inelasticity (ratio of the average lab energy of the primary outgoing particle to that of the incident particle), and a transverse momentum distribution of secondary particles independent of the energies of the incident and secondary particles.

Once the π-π elastic cross sections are known, one can quantitatively compare these predictions with experimental data. At small energy we approximate the π-π elastic cross section by the π-π total cross section, which by the optical theorem is just the imaginary part of the forward elastic amplitude. We then represent this amplitude by the Veneziano formula. Including only the ρ, f, and g contributions (and their daughters[1]), the model predicts $\alpha_P(0) = 0.3$, $\alpha_\rho(0) = 0.16$, $\langle n \rangle = 0.7 \ln s$, $(\bar{E}/E_i)_{N-N} = 0.9$, $\langle P_T \rangle = 0.4$ (for a pair of pions). The corresponding experiment numbers are $\alpha_P(0) \approx 1$, $\alpha_\rho(0) \approx 0.5$, $\langle n \rangle \approx 2 \ln s$, $(\bar{E}/E_i)_{N-N} \approx 0.6$, $\langle P_T \rangle \approx 0.35$ (for a single pion).

In order to generate the observed output P and ρ intercepts, the kernel of the integral equation in this model must be multiplied by a factor of about three to five. To improve these predictions, work is in progress to consider the off-shell effects and the high subenergy contribution, and to take into account the complete symmetrization of the secondary particles (i.e., to include nonplanar diagrams).

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

DYNAMICAL REGGE TRAJECTORIES FROM THE MULTIPERIPHERAL MODEL

J. S. Ball,*† G. Marchesini,† and Kent Jolley†

A multiperipheral model, based on one-pion-exchange dominance of low-momentum-transfer processes, is used to study the dynamical origin of the leading Regge trajectories that are coupled to the two-pion system. A Bethe-Salpeter technique is used to calculate the leading singularities in the angular momentum plane from an input interaction that is determined by the observed low energy

pion-pion scattering amplitude plus the high energy contribution of the Pomeranchon. The solution leads to a partial bootstrap system for which the parameters of the Pomeranchon are determined self-consistently. The output trajectories are found to correspond to what we conjecture are effective Regge trajectories, which in reality correspond to both Regge-pole and cut contributions. The trajectories and coupling constants obtained seem to be in reasonable agreement with the values allowed by experiment. We assume that the amplitude, which contains a pole and a cut due to the P, may be well represented by a single complex trajectory, corresponding to a pole on the second sheet of the angular momentum plane.

This work is continuing in two directions: (a) more careful study of the generation of the effective pole in the angular momentum plane and the analogy with the dynamical generation of the resonances in the energy plane, (b) direct application of the multiperipheral model in order to compute relevant physical quantities such as the pion transverse and longitudinal momentum distribution.

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KINEMATIC SINGULARITIES OF MULTIPARTICLE PROCESSES

Bengt E. Y. Svensson*

For the 2-to-2 particle reactions, Trueman has shown[1] that the kinematic singularities of helicity amplitudes may be understood as due to the singular behavior of the Lorentz group parameters--i.e., boost and rotation angles--on certain manifolds in the space of the invariant variables. In two papers,[2] I have shown how this idea may be generalized to give the kinematic singularities of multiparticle amplitudes also. Of particular interest here are the amplitudes introduced by Bali, Chew, and Pignotti (BCP amplitudes),[3] since they are the most convenient ones for formulating multiperipheral models, in particular multi-Regge ones. In fact, I have found that the structures of the kinematic singularities for the BCP amplitudes are the same as those for the 2-to-2 particle amplitudes, whenever such a comparison makes sense. My result should be suitable for analyzing kinematic constraints in a multi-Regge model, incorporating problems due to spin.

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1. T. L. Trueman, Phys. Rev. 173, 1684 (1968).
2. Bengt E. Y. Svensson, On Kinematic Singularities of Helicity Amplitudes for Multiparticle Reactions, University of California–Berkeley preprint; Bengt E. Y. Svensson, On Kinematic Singularities of the Bali-Chew-Pignotti Multiparticle Amplitudes, UCRL-19262, July 1969.
3. N. F. Bali, G. F. Chew, and A. Pignotti, Phys. Rev. 163, 1572 (1967).

PHENOMENOLOGY OF MULTIPARTICLE PRODUCTION

Edmond L. Berger*

Research continued on the phenomenological understanding of multipion production in high-energy proton-proton reactions. Multiperipheral pion-exchange diagrams were studied. Primary emphasis was placed on developing a description of multiparticle production consistent with present understanding of two-body reaction studies.

For example, parameters used to describe distributions in subenergy and momentum-transfer variables, as well as absolute normalization constants, are taken from quasi-two-body fits whenever possible. This work is an attempt to extend the results of earlier work[1] to higher multiplicity processes.

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Group, High Energy Physics Division, Argonne National Laboratory, Argonne, Illinois 60440.
1. E. L. Berger, Phys. Rev. 179, 1567 (1969).

PERIPHERAL FORWARD PEAKS IN REACTIONS FOR WHICH SINGLE MESON EXCHANGE IS FORBIDDEN

Edmond L. Berger*

Research was begun on dynamical mechanisms responsible for production of peripheral forward peaks in those quasi two-body reactions for which single meson exchange is not allowed. Exchange of exotic meson states is discounted. It has been shown[1] that peripheral peaks of the type observed are generated as reflections from competing allowed processes. Calculated magnitudes and shapes are consistent with available data. Further work is in progress. Box diagrams involving allowed exchange of two mesons are being studied. Final-state interaction schemes are also under investigation.

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1. E. L. Berger, Exotic Exchange or Kinematical Reflections? (UCRL-19271, July 1969), submitted to Phys. Rev. Letters.

MULTIPERIPHERAL MODEL AND THE ω TRAJECTORY

Peter Di-hsian Ting

The multiperipheral model of Chew, Goldberger, and Low[1] is used to generate the ω trajectory by combining with the phenomenological model of Chan, Loskiewicz, and Allison (CLA).[2] The kernel we use in the integral equation is in the CLA form

$$\left(\frac{g\, s_i + ac}{s_i + a}\right) \quad \left(\frac{s_i + a}{a}\right)^{\alpha_0} \quad \left(\frac{s_i + b}{b}\right)^{\alpha' t_i} ,$$

where α_0 and α' are respectively the intercept and the slope of the nucleon trajectory at $t = 0$. We believe that, by summing all the diagrams $N\bar{N} \to n\pi$ $(n = 2, 3, 4, \cdots)$, we will get $\beta_{N\bar{N}\omega}(s/s_0)^{\alpha_\omega(t)}$. This is just the ω-trajectory contribution to the elastic amplitude. In order to get this result we will use the computer to solve the eigenvalue problem, where all the constants appearing in the kernel, such as g, a, b, and c, have been fixed by previous fittings.

1. G. F. Chew, M. Goldberger, and F. Low, Phys. Rev. Letters 22, 208 (1969).
2. Hong-Mo Chan, J. Loskiewicz, and W. W. M. Allison, Nuovo Cimento 57A, 93 (1968).

GLOSSARY FOR REGGE POLE THEORY

J. D. Jackson

In the process of revison of the Lund review paper[1] for publication it was decided to supplement the text with a glossary of Regge pole terms and other definitions. The glossary seemed sufficiently valuable to be issued as a separate report.[2]

1. J. D. Jackson, Models for High Energy Processes, Rev. Modern Phys. (1970).
2. J. D. Jackson, Glossary for Regge Pole Theory, UCRL-19351, Sept. 24, 1969.

MODIFIED REGGE EXPANSION AND CROSSING

Chun-fai Chan

An attempt has been made to modify the s-channel Regge expansion so that the singular but physical points, $z_s = \pm 1$, are included in the region of convergence of the expansion. Using a method devised by W. Drechsler,[1] one subtracts out the logarithmic singularity and some other terms from the Legendre function $P_{\alpha(s)}(-z_s)$ (in the case of spin, the d function) to eliminate the divergence. The conditions for validity of the expansion are essentially the same as before. One finds that the s-channel resonance pole behavior

and the cross-channel high energy power behavior are unaltered, provided that the leading pole has $\mathrm{Re}\,\alpha(s) > 0$ for $s \lesssim 0$. No cuts or fixed poles are introduced into the j plane. Thus, as $s \to \infty$ and $z_s \to 1 + 0(t/s)$, one finds that each Regge pole term in the expansion gives a finite contribution, $\beta_i(s)\,\Gamma'[-\alpha_i(s)]/\Gamma[-\alpha_i(s)]$ [except when $\alpha_i(s)$ = integer], to the amplitude. If this expression for the amplitude is equated with the Regge power behavior obtained from crossing from the t-channel Regge expansion (signature has been ignored), one finds that the sum of the background term, plus all the simple pole terms described above (which depend on s alone), plus a term which goes like $0(t/s)$, yields the Regge power behavior $\beta(t)\, s^{\alpha(t)}$.

If one considers forward scattering, t = 0, and uses a model for β--e.g., β from the Veneziano model--then one finds an equation for the trajectory as a function of s.

1. W. Drechsler, Nuovo Cimento 61A, 1 (1969).

SKELETONS IN THE REGGE CUPBOARD*

Geoffrey C. Fox†

The energy dependence of virtually all experimental $d\sigma/dt$ data has been plotted as a function of t. This is compared with various Regge pole and cut models. It is shown that several favorite cut models fare badly in this comparison. (In particular the hybrid model and the Michigan strong-absorption model disagree with such data.) Juxtaposition of the curves for photoproduction and strong interactions emphasizes the strong evidence for fixed poles and double poles in the former processes. This is particularly striking for π^0 photoproduction, which is predicted to be similar to πN CEX.

I have compared Reggeized absorption-model fits with $\pi N \to \rho N$ and ωN and photoproduction. All these reactions need twice the expected absorption constant (it is true in all reactions that the needed absorption constant is never less than expected--sic transit pure pole models--and in 0^- meson-production process and elastic scattering the needed value agrees well with the canonical $\sigma_t/4\pi A$). We propose a quest for the π trajectory in $\pi^- p \to (\pi\pi)_{s\text{-wave}} n$, and show that absorption moves the $\alpha = -1$ zero from -1 to $t = -0.4$ $(\mathrm{GeV}/c)^2$.

*Work described at the Stony Brook Conference, and, I hope, written up in the proceedings thereof.

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DIFFRACTIVE EXCITATION OF HADRON RESONANCES

C. Quigg

The experimental data on diffractive resonance production are being examined to determine the implications of these data for the formulation of Regge cut models. In absorptive cut models of the most conventional kind, the absorbed amplitude is obtained from a convolution of the input Regge amplitude with an elastic scattering amplitude. It has been argued[1] that the elastic amplitude in this convolution integral should be replaced by a total Pomeranchuk exchange amplitude, which describes both elastic scattering and diffractive excitation. In the "Michigan Model"[1] this total Pomeranchuk exchange amplitude is taken to be equal to twice the elastic amplitude. In view of the apparent phenomenological liabilities of this model[2] it is of some interest to check the empirical basis for its assumptions. I also expect that the results of this study will be of value in creating more general cut models, based on a Reggeon calculus.

1. F. Henyey, G. L. Kane, J. Pumplin, and M. H. Ross, Phys. Rev. 182, 1579 (1969).
2. G. C. Fox, invited talk at the Stony Brook Conference on High Energy Collisions, and

"Skeletons in the Regge Cupboard," in this report.

HIGH ENERGY REGGE-POLE MODELS FOR $\pi^{\pm}p$, $K^{\pm}p$, AND $p^{\pm}p$ SCATTERING

D. Austin,* W. Greiman,† and W. Rarita

We are investigating several Regge-pole parameterizations to fit the new data becoming available in $\pi^{\pm}p$, $K^{\pm}p$, and $p^{\pm}p$. We mention some of the more interesting information: (a) the elastic p-p differential cross section from Serpukhov at 12 to 70 GeV, (b) the preliminary polarizations at 6 GeV/c for $\pi^{\pm}p$, $K^{\pm}p$, and $p^{\pm}p$ from the CERN-Orsay-Pisa group (work is also proceeding at 10, 14, and 15 GeV/c), (c) accurate p-p polarization at 6 GeV/c that goes down past the crossover momentum-transfer point, (d) the published precisely measured $\bar{p}p$ elastic differential cross sections[1] at 8 and 16 GeV/c, and (e) the A and R for elastic $\pi^{-}p$ at 6 GeV/c.

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1. D. Birnbaum et al., Phys. Rev. Letters 23, 663 (1969).

EXCHANGE-DEGENERATE REGGE TRAJECTORIES AND MESON-NUCLEON CHARGE-EXCHANGE SCATTERING*

Akbar Ahmadzadeh† and William B. Kaufman†

Based on exchange degeneracy and SU(3) symmetry, a Regge pole model is given that fits the differential cross sections for pion-nucleon and kaon-nucleon charge exchange and η production as well as polarization in $\pi^{-}p \to \pi^{0}n$. Besides the ρ-A_2 trajectory, a conspiring and exchange-degenerate ρ'-A_2' trajectory with the same slope as ρ-A_2 but with intercept near zero is taken into account. The residues are assumed to have $1/\Gamma(\alpha)$ behavior. A four-parameter fit gives good agreement with the experimental data.

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EXCHANGE DEGENERACY AND PARITY

R. H. Capps* and L. K. Chavda*

A useful hypothesis in recent hadron physics is the hypothesis that the imaginary parts of the contributions of Regge trajectories of opposite signatures cancel in hadron-hadron amplitudes of internal quantum numbers for which no resonances exist. We would like to extend the principle to states for which there are resonances of one parity only. An example is $\pi^{+}p$ scattering. It is expected that the principle will lead to relations between the residues of Regge trajectories in the two crossed channels. In order to apply the principle, one must make a specific assumption about the forms of the Regge terms in the intermediate-energy region. The Veneziano form is one possible form. We are just beginning to study this problem.

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POINCARE PHENOMENOLOGY AND THE u = 0 CROSS-CHANNEL PION-NUCLEON EXPANSION

Edward O. Thorland*

A review was made of the Poincaré group and its irreducible unitary representations, with special emphasis on the spacelike and continuous-spin lightlike cases. Several Clebsch-Gordan coefficients were derived (in a general frame) in such a manner that their symmetry properties are easily obtained. The Clebsch-Gordan coefficients were applied in a general theory of partial-wave expansions which places cross-channel expansions on a level with the usual direct-channel expansion. A possible connection between the spacelike crossed expansion and Regge theory has been

investigated in some detail.

The timelike and lightlike cross-channel (u-channel) expansions for pion-nucleon elastic scattering were carefully investigated, particularly near u = 0. CERN phase-shift data were used in the numerical evaluation of the cross-channel partial-wave analysis. A simple behavior was found for the u = 0 amplitudes, which leads to the conclusion that this simple behavior implies the existence of "sharp" values of the interaction radius of the pion-nucleon system.

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EXCHANGE DEGENERACY AND THE Λ-Σ SPLITTING

Richard H. Capps*

The hypothesis is advanced that the sum of the imaginary parts of the baryon Regge contributions vanishes in meson-baryon scattering amplitudes of exotic internal quantum numbers (quantum numbers for which no resonances exist). This hypothesis is combined with the assumptions that all coupling constants satisfy exact SU(3) symmetry, and that the Σ-Λ mass splitting cannot be neglected, so that the Σ and Λ lie on different Regge trajectories. All possible partitions of the spin-parity $\frac{3}{2}^-$ Λ's and Σ's (belonging to an octet, singlet, and decuplet) to the two trajectories are considered. A set of consistency equations is derived. If the Λ(1520) is the only odd-parity baryon on the bottom Λ(1115) trajectory, and the Λ(1690) and one or two Σ's lie on the top trajectory, there is only one solution. This is compared with experiment. This work was started at Purdue University, and finished at the Lawrence Radiation Laboratory.

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DIFFICULTIES IN POLE EXTRAPOLATION FOR THE Δ TRAJECTORY

E. L. Berger,* G. C. Fox,† and C. Quigg

We have investigated the influence of absorptive corrections to the scattering amplitudes on the well-known problems[1] associated with extrapolation of Regge residue functions from the physical region of backward $\pi^- p$ scattering to the positive u ("baryon spectrum") region. Our preliminary results indicate that such corrections can mitigate but not eliminate the inconsistency between resonance widths and backscattering cross-section data. A brief account of progress to date was given[2] at the Boulder Conference, August 18-23, 1969. Further studies are under way.

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1. The problems encountered are described in E. L. Berger and G. C. Fox (UCRL-18886, May 1969), Phys. Rev. (to be published).
2. E. L. Berger and G. C. Fox, Pole Extrapolation in Meson-Nucleon Backward Scattering Using Veneziano Model Residues and Absorption, Argonne National Laboratory Preprint, 1969.

ELASTIC SCATTERING DATA

Geoffrey C. Fox* and C. Quigg

We have collected all existing high energy ($p_{lab} \gtrsim 2$ GeV/c) differential cross section data for the elastic scattering of $\pi^\pm p$, $K^\pm p$, pp, and $\bar{p}p$. For the benefit of others who wish to study these reactions, we have generated magnetic tapes containing coded instructions for making CalComp plots of $d\sigma/dt$ vs t, for $-t < 2\ (\mathrm{GeV/c})^2$. These tapes will be made available (within LRL) to anyone wishing to produce such plots.

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STUDY OF STRANGENESS EXCHANGE IN QUASI-TWO-BODY REACTIONS

G. C. Fox* and C. Quigg

We have studied all reactions that proceed by natural-parity strange-meson exchange. These reactions are of theoretical interest because only two (possibly exchange-degenerate) trajectories, $K^*(890)$ and $K^{**}(1400)$, can contribute to scattering amplitudes. We have investigated the phenomenological basis for exchange degeneracy of these trajectories, the validity of SU(3) symmetry for the three-body vertices, and the effects of absorptive corrections. Within the framework of SU(3), it is of interest to determine the D/F ratios for both flip and nonflip couplings of the trajectories. This information is particularly useful in trying to understand the anomalous[1] Λ^0/Σ^0 ratio observed in $\gamma p \to K^+Y^0$. A paper is in preparation.

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1. B. Richter, in Proceedings of the XIV International Conference on High Energy Physics, Vienna, 1968, p. 15.

THEORY OF ρ^0-ω INTERFERENCE IN $\pi^+\pi^-$ PRODUCTION

Alfred S. Goldhaber,* Geoffrey C. Fox,† and C. Quigg

The Coleman-Glashow model for ρ-ω mass mixing permits unambiguous analysis of recent $\pi^+\pi^-$ production data. Such data provide a determination of the relative phase of ρ and ω production amplitudes, in agreement with the prediction of a Regge model with exchange-degenerate trajectories. We explain the anomalously small width of the ρ measured in colliding-beams experiments. This portion of the work has been published.[1]

We have made detailed studies of the observability of the predicted effects in the $\pi^+\pi^-$ mass distribution, and find that resolution equal to the width of the ω meson is required for observation of details. Much more difficult is the experimental identification of interference in the three-pion decay mode: the largest effect is the modification of the ω-production t distribution. We are also studying the consequences of ρ-ω interference for the determination of vector meson-photon coupling constants. A paper is in preparation.

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†Present address: Cavendish Laboratory, Cambridge, England.

1. A. S. Goldhaber, G. C. Fox, and C. Quigg, Phys. Letters 30B, (1969).

NUCLEON-NUCLEON SCATTERING BELOW PION PRODUCTION

Ronald Bryan*†

Sudarshan's universal vector and axial-vector interaction model is tested against the low-energy nucleon-nucleon scattering data. It is found that the model is capable, in principle, of accounting for the data; but the ω-photon coupling, which for convenience has been set equal to the ρ-photon coupling, must be increased an order of magnitude in order that there be sufficient spin-orbit attraction. Moreover, it is found that two-pion and higher-exchange contributions are essential in providing sufficient intermediate-range central attraction. If the Schrödinger equation is used to unitarize the Born terms, then additional attraction may be required, such as results from $\sigma(715)$ or f^0 exchange.

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SPECTRAL FUNCTION SUM RULES AND IDENTITIES OF THE JACOBI TYPE

H. Genz*

Sum rules for baryon spectral functions

including the sum rule of Rothleitner and Sugawara [1] may be obtained by use of an algebraic identity of the Jacobi type (which contains anticommutators for fermion operators). The simplest two of these sum rules predict a $P_{11}(m > 1470)$ resonance from the existence of the four nucleon resonances $P_{11}(940)$, $P_{11}(1470)$, $S_{11}(1550)$, and $S_{11}(1710)$. By application of the same technique to the SU(2) $\otimes$ SU(2) currents, this time using the Jacobi identity itself, one obtains the Weinberg spectral function sum rules.[2-4]

*NATO Fellow.

1. J. Rothleitner, Nucl. Phys. B3, 89 (1967); M. Sugawara, Phys. Rev. 172, 1423 (1968).
2. S. Weinberg, Phys. Rev. Letters 18, 507 (1967).
3. S. L. Glashow, H. J. Schnitzer, and S. Weinberg, Phys. Rev. Letters 19, 139 (1967); R. Jackiw, Phys. Letters 27B, 96 (1968).
4. H. Genz, On Baryon Spectral Function Sum Rules (UCRL-19243, July 1969), Proceedings of the Boulder Summer Institute (to be published).

ASYMPTOTIC BEHAVIOR OF ELECTROPRODUCTION AMPLITUDES

Satoshi Matsuda* and Mahiko Suzuki †

Asymptotic behavior of electroproduction amplitudes has been calculated by use of a spectral representation for the solutions of the Bethe-Salpeter equation in the limit of q^2 ("photon mass") $\rightarrow \infty$ with (lab energy)/q^2 fixed and large. The results are compared with experiment and with existing theoretical arguments. It is pointed out that a mild q^2 dependence may be consistent with finite-energy sum rules. Asymptotic behavior of electroproduction amplitudes for one-hadron production processes are also found to be consistent with unitarity.

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PHOTOPRODUCTION SUM RULES

Bipin R. Desai*

Simple Regge pole models appear to be inconsistent with the experimental evidence for the absence of dips at points corresponding to the nonzeroes of ρ, ω, and nucleon trajectories in photoproduction reactions. On the other hand, the absorptive cut model seems to work, at least qualitatively. The cut model is being extensively investigated by using finite-energy sum rules for different photoproduction reactions in the forward and the backward directions.

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N/D BOOTSTRAP MODEL AND ONE-PION-EXCHANGE POTENTIAL

Chih Kwan Chen

A bootstrap model based on the one-pion-exchange processes, such as $\pi\rho$, NN, ($N\bar{N}$) elastic scattering, etc., is being investigated. The N/D method is being used with the simplifying assumption that only nearby singularities are important. Thus the one-pion-exchange potential will be used as the input. The possibility of generating the A_1 resonance in the $\pi\rho \rightarrow \pi\rho$ process will be investigated. The experimental data for NN elastic scattering at low energy will also be compared with the results of this bootstrap calculation.

OVERLAPPING RESONANCES AND THE A_2 MESON

Chun-fai Chan

A double spherical shell potential is used to investigate the s-wave scattering of two spinless particles. It is found that the S matrix can have complex poles that correspond to narrow resonance states occurring within the inner shell, and broad resonance states occurring between the two shells. If the

strength of the inner shell is reduced, then the narrow resonances get broader while the broad resonances get narrower. It can so happen that two poles, one narrow, one broad, become maximally overlapped, and the observed spectrum will be a symmetrical double-peak structure. Generalization to a two-channel case is under study.

For the A_2 meson, we consider a model based on two intersecting (in Re α only) Regge trajectories--one trajectory passing the A_2 position with normal slope (this is obtained from the high energy data fitting), one π_N-A_2 trajectory with slope about 3 GeV^{-2}. We hope that this can tell something about the partial width of the A_2 meson.

LOW-ENERGY PION-NUCLEON SCATTERING

Ronald A. Christensen

The off-shell behavior at low energies of the amplitude for $\pi N \rightarrow \pi N$ is being studied by using a power expansion in scalar invariants with coefficients constrained by crossing symmetry, current algebra, and PCAC to see if an improvement can be obtained for the fit to $\pi N \rightarrow \pi\pi N$ scattering data.

OFF-SHELL EQUIVALENT POTENTIAL MODELS

Ronald A. Christensen

The equivalent potential technique of Charap and Fubini,[1] Balazs,[2] and Finkelstein[3] is being applied to the scattering of spinless particles to study the possibility of using an extension of this technique to model the off-shell behavior of amplitudes. The principal interest is to see if a simple model can be constructed with reasonable off-shell behavior in the vicinity of an s-channel pole (even for $B \neq 0$), and also be extended smoothly to a low-order power expansion away from the pole.

1. J. M. Charap and S. P. Fubini, Nuovo Cimento 14, 540 (1959); 15, 73 (1960).
2. L. A. P. Balazs, Phys. Rev. 137, B1510 (1965).
3. J. Finkelstein, Phys. Rev. 145, 1185 (1966); 154, 1596 (1967).

ANALYSIS OF PION-HELIUM SCATTERING FOR THE PION CHARGE RADIUS

C. T. Mottershead

Pion-helium scattering data have been analyzed, assuming the pion charge distribution enters the calculation only via the effective Coulomb potential in a generalized Schrödinger equation. Boundary-condition methods are used to reduce the sensitivity of the result to the details of the pion-nucleus strong interaction. A surprisingly large pion radius of 2 to 3 F is found. A report on this work[1] has been submitted to the Physical Review.

1. C. T. Mottershead, Analysis of Pion-Helium Scattering for the Pion Charge Form Factor, UCRL-19216, June 1969.

PION-HELIUM SCATTERING

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

Work on the scattering of pions by helium reported in the preceding progress report is continuing. We believe the source of difference between the approaches of Mottershead[1] and Christensen[2] is the former author's neglect of pair-creation effects. Our own program will, of course, include them. It has been found that a separation of the effects of nuclear and Coulomb scattering can be achieved by using solutions of the Schrödinger equation that are determined exactly by their behavior at the origin rather than by using the scattering wave function (the Regge solution). Thus in the interior of the nuclear well the Coulomb effect is negligible, whereas outside it the opposite is true.

A program has been devised for the construction of "Regge Type" Coulomb functions.

With these and the corresponding nuclear functions a direct solution for the phase shifts can be worked out. Exploration of the same effects using the Schwinger[3] variational principle for scattering will also be undertaken.

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1. C. T. Mottershead, Analysis of Pion-Helium Scattering for the Pion Charge Form Factor, UCRL-19216, June 1969.
2. Ronald A. Christensen, Strong Pion-Alpha Scattering with Electromagnetic Corrections, UCRL-18881, May 8, 1969.
3. Philip Morse and Herman Feshbach, Methods of Theoretical Physics (McGraw-Hill Book Co., New York, 1953).

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 $K \to 3\pi$ from the viewpoint that it is caused only by dressing the bare weak interaction with strong final-state interactions. The method of calculation used is the Khuri-Treiman dispersion-relation approach. This approach requires the solving of a singular integral equation whose kernel is essentially the $\pi\pi$ scattering amplitude. A method for numerically solving singular integral equations on a computer has been devised and is being used. We would like to relate the slope of the Dalitz plot to low-energy $\pi\pi$ scattering parameters. Eventually we should like to take into account the fact that at low energies the $\pi^+\pi^-$ channel has a lower channel it can decay into, namely $2\pi^0$. This could produce an "electromagnetic correction" which would affect the Dalitz spectrum and also the branching ratios to the various 3π final states.

TEST OF CHEW-LOW EXTRAPOLATION FOR $\pi\pi$ CROSS SECTIONS

Geoffrey C. Fox* and Alfred S. Goldhaber†

The absorption model is used to provide "experimental data" regarding the known pole at the unphysical point, squared momentum transfer $= m_\pi^2$. This allows a test of the reliability of various extrapolation techniques applied to actual data on reactions presumed dominated by one-pion exchange.

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RELATIVISTIC QUARK MODEL BASED ON THE VENEZIANO REPRESENTATION. II. GENERAL TRAJECTORIES

Stanley Mandelstam

The model previously proposed is extended to include multiquark trajectories. Once any trajectories with more than a single quark and antiquark are included, it is necessary to include trajectories where the number of quarks plus the number of antiquarks, which we call the total quark number, is arbitrarily large. The necessary factorization properties of the multiparticle Veneziano amplitudes will hold provided the intercept of the leading trajectory is a polynomial function of the total quark number and the degeneracy of the levels on all but the leading trajectory will increase with the order of the polynomial. It is possible to construct two different models, depending on whether or not one allows nonplanar duality diagrams. The model with nonplanar diagrams resembles more closely the nonrelativistic harmonic-oscillator quark model, and the nonplanar duality diagrams must be associated with the nonplanar Veneziano amplitudes discussed in a previous paper. One can introduce SU(3) symmetry breaking by making the intercept depend on the numbers of strange and nonstrange quarks separately, and one then obtains a modified Gell-Mann–Okubo mass formula.

Work is continuing along similar lines. The above principles are being applied in more detail to baryon trajectories. Attempts are

being made to introduce symmetry breaking and to eliminate the ghosts.

QUARK MODEL AND THE VENEZIANO REPRESENTATION

Loh-ping Yu

Some studies based on the relativistic quark model [1] are being initiated. A method for introducing "exotic" mesons and baryons into the model by SU(6) symmetry breaking is being considered. The model will also be used in an attempt to fit π-N scattering, both forward and backward. Only semiquantitative or qualitative results are expected because of the exact SU(6) symmetry and the assumption of narrow resonances.

1. S. Mandelstam, Relativistic Quark Model Based on the Veneziano Representation, UCRL-19327, Sept. 1969.

PION-NUCLEON AND KAON-NUCLEON SCATTERING IN THE VENEZIANO MODEL

Edmond L. Berger* and Geoffrey C. Fox †

A study of meson-nucleon scattering within the framework of the Veneziano model has been used for a comprehensive phenomenological examination of the model for the cases of pion-nucleon and kaon-nucleon processes. We use invariant amplitudes constructed as sums of beta-function terms and attempt to fit, simultaneously, all the relevant high- and low-energy scattering data as well as the elastic widths of baryon resonances. We discuss a useful technique for insuring that the theoretical amplitudes will possess the observed spin and parity structure of the physical spectrum of baryon states.

Our main conclusions are:

(a) If the polynomial residue function suggested by the model is used in detailed fits to all πN backward data and elastic widths, then the model fails to provide an adequate extrapolation from the scattering data to the widths of the $\Delta_\delta(1238)$ and its recurrences, although acceptable agreement is found for the other trajectories. We also find that the residues of the πN trajectories are in marked disagreement with exchange degeneracy.

(b) Within a factor of two in amplitude, the model reproduces available KN charge-exchange data from threshold to the highest energy.

(c) Terms of a subsidiary nature in the Veneziano expansions enter with large multiplicative constant coefficients.

(d) The predicted duality relation between the s-channel (baryon) and the t-channel (meson) Regge poles is not supported quantitatively.

(e) A Pomeranchuk trajectory with normal slope $[\alpha_P' \approx 1\ (\mathrm{GeV}^{-2})]$ is consistent with both the Veneziano model and all data.

(f) The model does not provide any natural resolution of the difficulties inherent in classical Regge-pole model fits, and thus supports the view that Regge cuts are important. We are now studying the relationship of cuts to πN backward scattering data.

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APPLICATION OF THE VENEZIANO MODEL TO np → pn AND $p\bar{p} \to n\bar{n}$ SCATTERING

B. K. Pal

Work is in progress on the application of the Veneziano representation to np → pn and $p\bar{p} \to n\bar{n}$ scattering. Our purpose is to learn whether this model leads to better results and increased understanding of these processes. In this representation, exchange-degenerate and parity doublets occur in a natural way and the ghost parities are expected to be eliminated.

VENEZIANO REPRESENTATION

K. Tanaka*

It is becoming clear that in addition to the leading term the secondary terms in the Veneziano representation are necessary to account for various experimental data. The possible role of these secondary terms in meson-meson scattering is studied.

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*Supported by U. S. Atomic Energy Contract administered by Ohio State University, Columbus, Ohio 43210.

REVIEW OF RECENT WORK ON THE CROSSING-SYMMETRIC NARROW RESONANCE APPROXIMATION

D. Sivers* and Joel Yellin†

Recent work on general narrow resonance models, including the Veneziano formula and its various generalizations, is reviewed and discussed.

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N/D CALCULATION BASED UPON A POTENTIAL SUGGESTED BY THE VENEZIANO MODEL

Carleton DeTar

As part of an effort to understand the consistency of the Veneziano form as an approximate representation of the π-π scattering amplitude with the form obtained from strip model calculations, a study is under way to determine the feasibility of obtaining constraints upon the parameters of the ρ and Pomeranchuk trajectories through an N/D calculation, based upon a potential suggested by the Veneziano model. Elastic unitarity is imposed in a finite strip. Outside this strip, the partial-wave amplitudes are constrained to conform to the partial-wave projection of the Veneziano function, as was done by Atkinson et al.[1] Including the Pomeranchuk, as suggested by Wong,[2] we impose self-consistency of input and output trajectories.

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1. D. Atkinson et al., Phys. Letters 29B, 423 (1969); D. Atkinson and L. A. P. Balazs, A Unitarization of the Veneziano Model that Preserves Exact Crossing and Regge Behavior, Argonne National Laboratory Report, July 1969.

RENORMALIZATION OF REGGE TRAJECTORIES AND SINGULARITY STRUCTURE IN THEORIES OF THE KIKKAWA-SAKITA-VIRASORO TYPE

J. C. Polkinghorne*

An investigation was made of theories[1] that satisfy the duality principle using the Veneziano amplitude as a Born term.[2] The Regge pole terms in the asymptotic behavior are identified and transcendental equations written down to express the full renormalization of the leading trajectory. The amplitude is shown to possess the Landau-Cutkosky singularity structure corresponding to the poles lying on this trajectory. The consequences for the interpretation of the theory are discussed.

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*Present address: D. A. M. T. P., University of Cambridge, Cambridge, England.
1. K. Kikkawa, B. Sakita, and M. A. Virasoro, Phys. Rev. (to be published).
2. J. C. Polkinghorne, Renormalization of Regge Trajectories and Singularity Structure in Kikkawa-Sakita-Virasoro Type Theories, Phys. Rev. (to be published).

NEW APPROACH TO THE REGGEON CALCULUS

J. C. Polkinghorne*

Work has been begun on a new approach to the Reggeon calculus.[1] It makes use of the Veneziano model to represent the Reggeons. The integrals are written in terms of Sudakov variables and their asymptotic behavior evaluated, by using techniques previously developed for discussing the signature properties of Feynman integrals.[2] The method is more

transparent and reliable than earlier approaches and is particularly well adapted to evaluating complicated pinch effects and signature properties. The first results are being written up,[3] and further development will be undertaken.

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1. V. N. Gribov, Soviet Physics–JETP 26, 414 (1968).
2. J. C. Polkinghorne, Nuovo Cimento 56A, 755 (1968).
3. J. C. Polkinghorne, D. A. M. T. P. reports, in preparation.

SPIN AND INTERNAL SYMMETRY IN DUAL FEYNMAN THEORY

M. B. Halpern, S. A. Klein,* and J. A. Shapiro†

Spin and internal symmetry were incorporated into the recently proposed dual Feynman theory.[1] Classification of all graphs via the sewing procedure was emphasized, and it became explicit that the $\tilde{\tilde{U}}(12)$ theory keeps its symmetry (and its ghosts) to all orders. The pattern of the breakdown of exchange degeneracy was also discussed.

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†Physics Department, University of California–Berkeley.

1. K. Kikkawa, S. A. Klein, B. Sakita, and M. A. Virasoro, University of Wisconsin preprint COO-248, 1969.

DEVELOPMENTS IN DUAL RESONANCE MODELS

L. Caneschi* and G. Veneziano†

Work has continued in the direction of further developing an harmonic oscillator-like formalism for dual resonance models first introduced by S. Fubini, D. Gordon, and G. Veneziano (MIT) and by Y. Nambu (U. of Chicago).

In particular, in collaboration with A. Schwimmer (SLAC), we have been able to find an operator that is able to "twist around" the duality lines. This result has been applied to the calculation of the general symmetric three-resonance vertex of dual-resonance models. The above results will appear in a SLAC preprint shortly. Further applications, especially to the calculation of nonplanar diagrams, are now under study.

A second direction of work has been pursued in trying to calculate the two-particle discontinuity of the planar box diagram. There was some a priori feeling that such discontinuity was infinite at high energies and thus spoiled Regge behavior. Our preliminary results show that this is probably not the case, but a more careful study is still needed.

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REVIEW OF NARROW RESONANCE MODELS

Dennis Sivers* and Joel Yellin†

A review of the work done since that of Veneziano[1] on models in which the scattering amplitude contains poles on the real axis is in preparation. We explore the validity of such schemes and investigate the philosophy behind their use.

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†Present address: Institute for Advanced Study, Princeton, N. J. 08540.

1. Gabriele Veneziano, Nuovo Cimento 57, 190 (1968).

THRESHOLD EXPANSIONS AND THE SUZUKI MODEL

Dennis Sivers*

Threshold expansions for the Regge trajectory function, $\alpha(s)$, are investigated in conjunction with the Suzuki[2] model for the scattering amplitude. The work continues as difficult questions of duality, Riemann sheet

structure, and inelastic unitarity are explored.

*NSF Predoctoral Fellow.
1. Mahiko Suzuki, Phys. Rev. Letters 23, 205 (1969).

STRUCTURE AND CALCULATION OF RELATIVISTIC WAVE EQUATIONS

David Kershaw,* Herschel Snodgrass,* and Charles Zemach

A general procedure aimed at calculating energies, phase shifts, and wave functions for two-body relativistic wave equations (Bethe-Salpeter equations) has been devised. Application to bound states of spin zero particles has been completed and the work on scattering states is partially done. The method involves matching a suitable selection of solutions regular at infinity to solutions regular at the origin, dependent on the interactions generated by power series. The method also provides off-shell scattering amplitudes and other parameters relevant to a bootstrap program such as "output" coupling constants. An elementary, spin zero bootstrap calculation has been carried out. The Wick rotation, and hence feasibility of approximation by truncation of a four-dimensional spherical harmonic expansion, has been established for coordinate space wave functions at any energy. The Green's function for the truncated differential equation is seen to be a Gaussian quadrature applied to the truncation of the exact Green's function, showing that the truncated integral equation is more accurate than the truncated differential equation. The structure of the radial and polar lines has been studied. The bound states without polar nodes are the relativistic generalizations of ordinary two-body states, and their number is related to zero-energy phase shifts via the Levinson theorem. The other ("abnormal") bound states represent binding of a mixture of off-energy-shell particles and are relevant to coupling through the relativistic, retarded interaction of two-particle states to many-particle states. The details depend on analysis of the special functions relevant to these wave equations, which are generalizations of Bessel functions.

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RELATIVISTIC WAVE EQUATION

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

We have studied the nature of the solutions of an equation proposed by Bakamjian and Thomas[1] for an interaction due to the time component of a massive vector field (cutoff Coulomb interaction). This equation may be derived from quantum field theory by neglecting multiparticle states or may be deduced as an approximation to the Klein-Gordon equation.[2]

An interesting feature of the integral equation is that the kernel is not of the Fredholm type. As a consequence the behavior of the momentum-space wave function is unconventional; i.e., it is not determined solely by the angular momentum. For attractive potentials which are not too strong and for repulsive potentials the s-wave amplitude falls as $p^{\xi-1}$, where $\frac{3}{2} < \xi < 2$ in the attractive case and $\xi > 2$ in the repulsive case. In order to define unique solutions it is necessary to impose square integrability of the wave function[3] about the origin in coordinate space. For very strong attractive potentials ξ becomes complex and both ξ and ξ^* are possibilities. In this case $\mathrm{Re}\,\xi = 3/2$ and the integrability condition does not suffice to determine the solution. A detailed numerical study of the solutions of the integral equation is under way.

1. B. Bakamjian and L. H. Thomas, Phys. Rev. 92, 1300 (1953).
2. H. Feshbach and F. Villars, Rev. Mod. Physics 30, 24 (1958).
3. This has been called the von Neuman condition. See K. M. Case, Phys. Rev. 80, 797 (1950).

VARIATIONAL PRINCIPLE FOR THREE-PARTICLE SCATTERING*

Jon Wright†

A variational principle has been derived for the scattering of three-particle systems. In order for variational principles to work, it is necessary to have trial functions that approximate the behavior of the exact wave function. For one-particle scattering off a bound state of two other particles, where a breakup process is possible, it is hard to describe the correlations between the pairs of particles for the outgoing wave. We have derived a principle analogous to the Schwinger principle, which provides a natural damping at large distances in one coordinate so that it is not necessary to describe these correlations. However, it is necessary to know the correct asymptotic behavior for either rearrangement or elastic scattering. This feature is the same as for the ordinary two-particle Kohn principle. It is possible to remove even this restriction on the asymptotic behavior, but the additional complications appear to make this further step impractical. The method is currently being tested with a separable-potential model.

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*Work performed in collaboration with Dr. Leonard Schlessinger at the University of Illinois.
†University of Illinois, Urbana.

DIRAC MATRICES FOR ANY SPIN

T. J. Nelson*†

In the preceding quarterly report a formula for $S^+(N) = \hat{p}_{i_1}\hat{p}_{i_2}\cdots\hat{p}_{i_N} S^+_{4\cdots 4 i_1\cdots i_N}$, which is a polynomial of degree N in the spin matrix $z = \vec{s}\cdot\vec{p}$, was given. The covariantly defined Lorentz spin tensors $S^+_{\mu_1\cdots\mu_{2s}}$ are easily extracted by differentiating away the $\vec{p}$'s in $p^N S^+(N)$. The generalized Dirac matrices are simply related to these spin tensors and their Hermitian conjugates. It has now been found that the spin tensors that are irreducible under the rotation group are derived from the polynomials

$$O^+(N) = \sum_{j=0(\frac{1}{2})}^{N/2} \frac{2^{2j}\Gamma(\frac{N}{2}+j+\frac{1}{2})}{\Gamma(\frac{N}{2}-j+1)\,\Gamma(2j+1)} S^+(2j).$$

This form was discovered by using the known four-dimensional tracelessness of $S^+_{\mu_1\cdots\mu_{2s}}$. If the inverse of this expansion could be achieved it could prove useful in the treatment of electromagnetic interactions with high-spin particles.

In exploring the mathematical properties of the polynomials $S^+(N)$ we define

$$p_n^{\,s}(z) = (-i)^n[\Gamma(2s+1)/\Gamma(2s-n+1)]\, S^+(n).$$

The polynomials $p_n^{\,s}$ satisfy the recursion relation

$$p_{n+1}^{\,s}(z) = 2z\, P_n^{\,s}(z) - n(2s-n+1)\, P_{n-1}^{\,s}(z).$$

It has been found that the derivative with respect to z possesses the expansion

$$\frac{d\,P_n^{\,s}(z)}{dz} = \sum_{j=0(\frac{1}{2})}^{(n-1)/2} \frac{2\Gamma(n+1)}{\Gamma(2j+1)(n-2j)} P_{2j}^{\,s}(z),$$

which has the remarkable property that the coefficients are independent of the spin s. In future work the significance of this result will be explored, and it is hoped that this will lead to connections of these polynomials with other functions that arise in studies of the Lorentz group.

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RELATIVISTIC EIKONAL APPROXIMATION

R. L. Sugar*

A study is being made of the scattering of particles that interact via the exchange of

quanta whose lines can be crossed in all possible ways. It is well known that for the two-body problem one obtains a relativistic version of the eikonal approximation at large energies and small momentum transfers. We have shown that a similar result holds for the scattering of bound systems. The model is presently being extended to the region of large momentum transfers. Experience with nonrelativistic potential scattering indicates that the scattering amplitude should be dominated by the Regge cut diagrams in this region and that one should obtain a simple model of these cuts.

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DEVELOPMENT OF AN S-MATRIX THEORY BASED ON THE CALCULUS OF FINITE DIFFERENCES

M. DerSarkissian* and T. J. Nelson†

We investigate the possibility of constructing an S-matrix theory in which partial-wave expansions are made in terms of the spin-matrix polynomials:

$$W_n(z) = \Gamma(z + \tfrac{n}{2} + 1)/\Gamma(z - \tfrac{n}{2} + \tfrac{1}{2}).$$

The technique employed to project an arbitrary function of z onto this basis is found in the calculus of finite differences.

In this preliminary treatment, we first present the mathematical properties of the expansion, showing how analytic continuation into the complex n plane may be done. We then go on to discuss the possibility of constructing a bootstrap dynamics based on analyticity, unitarity, and crossing symmetry.

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NONANALYTIC S MATRIX

J. C. Polkinghorne*

Work begun with collaborators in Cambridge was completed.[1] It is shown that the theory recently proposed by Lee and Wick[2] achieves unitarity at the expense of analyticity. A covariant formulation of the theory is given in terms of Feynman integrals, and examples are investigated of points of nonanalyticity and of singularity on mixed-α arcs of Landau curves. It is shown that the requirement of unitarity does not unambiguously determine the form of the theory. The original Lee-Wick prescription is shown to be, in general, noncovariant in that it makes a frame-dependent resolution of these ambiguities.

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*Present address: D. A. M. T. P., University of Cambridge, Cambridge, England.
1. Work performed in collaboration with R. E. Cutkosky, P. V. Landshoff, and D. I. Olive; see R. E. Cutkosky, P. V. Landshoff, D. I. Olive, and J. C. Polkinghorne, A Non-Analytic S-Matrix, Cambridge Preprint DAMTP 69/25 and Nucl. Phys. (to be published).
2. T. D. Lee and G. C. Wick, Nucl. Phys. B9, 209 (1969).

ANALYTIC S-MATRIX THEORY

Ralph F. Guertin*

Preparations are being made for further investigation into the relationship between macroscopic causality conditions and the analytic properties of scattering amplitudes.

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*Supported by U. S. Air Force Contract AF-AFOSR-68-1471 administered by Physics Department, University of California–Berkeley.

REMARKS ON LOCAL LORENTZ COVARIANCE*

H. Genz†

Consequences of Lorentz covariance and the Schwinger condition for commutators of

the symmetry energy-momentum tensor with fields of spins 0, 1/2, 1, and 2 are investigated. A paper on the subject is in preparation.

*This work was performed in collaboration with J. Katz, Purdue University, Lafayette, Indiana 47907.
†NATO Postdoctoral Fellow.

ON CURRENT-FIELD IDENTITIES*

H. Genz †

The spectral representation is used to show that Lagrangian models of current-field identities require couplings containing derivatives of the pion field, unless the pion is free in the model. Additional conditions equivalent to this are given. We also find[1] that the vacuum expectation value of the σ term is nonvanishing unless the current is conserved and that a nonconserved charge cannot annihilate the vacuum (as stated by Coleman's theorem[2]). This work is described in a Purdue University Preprint.

*This work was performed in collaboration with J. Katz, Purdue University, Lafayette, Indiana 47907.
†NATO Postdoctoral Fellow.
1. H. Genz, On the Vacuum Expectation Value of the σ Term. Preprint: II. Institut für Theoretische Physik der Universität Hamburg, and Z. Physik (to be published).
2. S. Coleman, Phys. Letters 19, 144 (1965) and J. Math. Phys. 1, 787 (1966).

HAAG'S AND COLEMAN'S THEOREMS AT INFINITE MOMENTUM

C. Garwin

It is shown that neither Haag's theorem nor Coleman's theorem holds in the infinite momentum reference frame: it is possible to formulate a nontrivial (not equivalent to a free field) relativistic field theory in Fock space at infinite momentum in which a charge that annihilates the vacuum is not necessarily independent of time. Both theorems fail because vacuum-creation graphs vanish at infinite momentum (at least for a $\lambda\phi^3$ theory such as is considered).

COMPUTER PROGRAM FOR ARBITRARY 3n-j SYMBOLS

Joel A. Shapiro*

A program to calculate an arbitrary 3n-j program, given its diagram, has been written.[1]

*Department of Physics, University of California—Berkeley.
1. Joel Shapiro, Arbitrary 3n-j Symbols for SU(2), UCRL-19310, August 20, 1969.

STUDIES IN THE ROTATION AND LORENTZ SYMMETRIES OF SCATTERING AMPLITUDES

Kuo-hsiang Wang*

A general study of the space-time symmetries of the scattering amplitude is made. The scattering amplitude in the c.m. frame has O(2, 1) symmetry in the physical region of the crossed channels. By working in this frame, we can use the same definition of the helicity as in the usual angular-momentum analysis. In the pairwise equal-mass case the helicity amplitude in the forward scattering region of the crossed channels has O(2, 2) symmetry in the c.m. frame, and O(3, 1) symmetry in the brick-wall frame. We apply an O(2, 2) expansion to a multiparticle system. We also continue the O(4) expansion in the brick-wall frame in the O(3, 1) region, and show the equivalence between the O(4) expansion and the O(3, 1) expansion. Finally, we point out the difference between the implications of the three-dimensional and four dimensional symmetries.

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THE CLEBSCH-GORDAN SERIES AND THE CLEBSCH-GORDAN COEFFICIENTS OF O(2, 1) AND SU(1, 1)

Kuo-hsiang Wang*

The Clebsch-Gordan series of the O(2, 1) group and its covering group SU(1, 1) for all cases except that of the supplemental series are derived. The continuable Clebsch-Gordan coefficients (or equivalently, the Wigner coefficients) are explicitly expressed in terms of the generalized hypergeometric function ${}_3F_2$. The spectra in the decomposition of the product of the two principal series are discussed. The applications to the unitary irreducible representation of O(2, 2) are also studied.

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DIGESTING FEYNMAN INTEGRALS

Charles Schwartz

Some progress has been made on the program of developing general and efficient numerical procedures for evaluating the multiple integrals that occur in complicated Feynman diagrams.

CURRENTS AND DUAL n-POINT FUNCTIONS

K. Bardakci and Daniel Z. Freedman*

An investigation of mathematical models for n-point amplitudes with scalar and vector currents among their external lines was begun. For such amplitudes one requires the appropriate current-algebra divergence conditions to be satisfied, as well as duality and factorization properties similar to those of n-point hadronic functions. A seemingly natural method for defining n-point functions with external scalar currents, first proposed by H. Sugawara,[1] was shown to factorize inconsistently and probably must be abandoned as the basis for constructing current algebras. A set of n-point functions was constructed that satisfy neatly the divergence conditions of a local vector-scalar current algebra. The vector current in this model is essentially structureless, and the scalar current is pole dominated. There seems to be just enough factorization in the model to define a consistent resonance-dominated saturation scheme for this current algebra.

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1. H. Sugawara, Tokyo University of Education preprint, 1969.

ALGEBRAIC STRUCTURE OF CURRENT ALGEBRA AND SUPERCONVERGENCE SUM RULES AND INFINITE MOMENTUM METHOD

Sun-Sheng Shei

The formulas for the algebraic structure of current algebra and superconvergence sum rules derived previously by Weinberg are extended to the case of the massive pion by use of the infinite momentum method. It is shown that the formulas are closely related to the absence of the T = 2 part in some double commutation relations between the axial charges $Q_5{}^a$, $Q_5{}^b$ and the generators of inhomogeneous Lorentz transformations. Some possible generalizations of the present method are under investigation.

VECTOR CURRENTS IN REGGEIZED ZERO-WIDTH MODELS

Richard C. Brower* and J. H. Weis

Work is proceeding on a study of vector currents and current algebra in Reggeized zero-width models and, in particular, the generalized Veneziano model. A number of general properties in such models have been discussed.[1] A leading-order Veneziano model consistent with current algebra has been proposed.[2] In this model the form factors have

only single vector-meson poles, and factorization holds only for leading trajectories. We believe the dynamical requirement of factorization will require form factors with many vector-meson poles that decrease rapidly for large q^2. We are presently studying this problem from several points of view. On the other hand, without the imposition of factorization we can generalize the results of Ref. 2 to arbitrary form factors while retaining current algebra.

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*Present address: Massachusetts Institute of Technology, Cambridge, Massachusetts 02139.
1. R. C. Brower and J. H. Weis, Vector Currents and Current Algebra. I. Duality and Zero-Width Models, Phys. Rev. (to be published).
2. R. C. Brower and J. H. Weis, Vector Currents and Current Algebra. II. An N-Point Beta-Function Model, Phys. Rev. (to be published).

CURRENT ALGEBRA

Perry Shers

Detailed numerical consequences of the previously described method of computing corrections in the physical region to the low-energy theorems for pion-nucleon scattering obtained from PCAC and the algebra of charges are being extracted. The incorporation of exact results of crossing and analyticity, in addition to improving the plausibility of some of the approximations used, has also enhanced the feasibility of the checks now being made of their internal consistency and of that of the extrapolations in the mass of the pion.

STRONG-INTERACTION SUM RULES

Perry Shers

Partial-wave analogues of the ordinary finite-energy sum rules are being investigated.

PION PHOTOPRODUCTION AND FINITE-ENERGY SUM RULES

J. D. Jackson and C. Quigg

Work continued intermittently on the problem of high energy photoproduction of charged and neutral pions, using Regge poles plus Regge cuts generated by the recipe of the absorptive model. Attention was paid to (a) the π^+/π^- ratio as a function of momentum transfer, (b) the photoproduction of positive pions from polarized protons, and (c) extension of the "pseudomodel" to make predictions at larger t values and for polarized proton targets. Some aspects of this work are currently being written up. The original results have been published.[1]

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1. J. D. Jackson and C. Quigg, Charged Pion Photoproduction and Finite Energy Sum Rules, Phys. Letters 29B, 236 (1969).

MODELS FOR HIGH-ENERGY PROCESSES

J. D. Jackson

In connection with the presentation of a review talk on high-energy phenomenology at the Lund International Conference on Elementary Particles, June 25-July 1, 1969, an extensive review[1] of current theoretical models and their comparison with experiment was prepared.

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1. J. D. Jackson, Models for High-Energy Processes, Rev. Mod. Phys. (to be published).

APPLICATION OF FINITE-ENERGY SUM RULES TO THE REACTION $K^-n \to \pi^-\Lambda$

R. D. Field and C. Sorensen

The duality diagram for the reaction $K^-n \to \pi^-\Lambda$ is nonplanar. If we adopt Harari's viewpoint[1] both amplitudes A' and B are

expected to be purely real at high energies. Hence, we would predict no polarization of the Λ particle at high energies. However, recent experiments at 3 and 4.5 GeV/c[2, 3] show a large positive polarization over a wide range of $|t|$.

Inspired by the above inconsistency and the fact that there has been little work done on the application of finite-energy sum rules to inelastic reactions, we have undertaken a FESR analysis of the reaction $K^- n \to \pi^- \Lambda$. Our efforts to date have been limited to a narrow resonance approximation. We hope to learn more about the possible exchange degeneracy of the $K^*(890)$ and $K^*(1420)$ trajectories, and hope also to predict the polarization of the Λ particle at high energies.

1. H. Harari, Phys. Rev. Letters 22, 562 (1969).
2. Barloutaud et al., Nucl. Phys. B9, 493 (1969).
3. Yen et al., Phys. Rev. Letters 22, 963 (1969).

VENEZIANO-LIKE NONSTRONG AMPLITUDES FOR THE AXIAL CURRENT CONSISTENT WITH CURRENT ALGEBRA AND THE ADLER CONSISTENCY CONDITION

Fred Cooper*

Using spurion techniques on the five-point function of Bardakci-Ruegg, we are able to construct amplitudes for the process $A + \pi \to \pi\pi$ that are crossing symmetric and have the correct asymptotic behavior and pole structure. Going to the π, A_1, and A_1 daughter poles, we obtain strong-interaction Veneziano-type amplitudes satisfying the Adler condition. Using soft pion techniques, we obtain a plausible expression for the pion form factor in terms of one parameter related to the $A_1 \rho \pi$ s-wave coupling constant.

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n-POINT PION FUNCTIONS

Fred Cooper*

An attempt is being made to construct n-point functions for pions that satisfy the Adler consistency condition.

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VENEZIANO MODELS FOR VIRTUAL COMPTON SCATTERING

Richard C. Brower,* Arnulf Rabl,† and J. H. Weis

Recently proposed Veneziano-type models for Compton scattering of neutral and charged currents are studied. Current commutators, sum rules, large q^2 behavior, and factorizability are investigated. A new model is proposed which has good behavior in all these respects. Electroproduction phenomenology and electromagnetic mass differences are discussed.

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II. PHYSICS OF WEAK AND ELECTROMAGNETIC INTERACTIONS

WEAK RADIATIVE DECAY OF HYPERONS

K. Tanaka*

The decay mode $\Sigma^+ \to p + \gamma$ has recently become prominent because, its branching ratio being 0.2%, it is accessible to various new ideas in elementary particle physics. It is an unusual $\Delta S = 1$, $\Delta Q = 0$ decay mode and owes its existence to a combined weak and electromagnetic interaction. A survey of the theoretical papers on these decay modes is being prepared.

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UNITARITY RELATIONS AND S-MATRIX FORMULATION OF K^0 MESON DECAYS

Lincoln Wolfenstein*

The recent S-matrix formulation of the K^0 system by McVoy and Durand has been reviewed to show more clearly its equivalence to the usual Wigner-Weisskopf method. This material has been submitted as a comment to the Physical Review. The application of the unitarity relation to the ρ-ω interference has also been considered.

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INDUCED PSEUDOSCALAR COUPLING*

Lincoln Wolfenstein†

The accuracy of the standard prediction for the value of the induced pseudoscalar coupling constant G_P in muon capture has been reviewed in the light of the recent analysis of the Goldberger-Treiman relation by Pagels. It is shown that there is a small correction to the usual formula related to the axial-vector form factor. With this correction the prediction for G_P should be more accurate than the Goldberger-Treiman relation.

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*Work included in a review talk given at the Third International Conference on High Energy and Nuclear Structure held at Columbia University in September 1969.
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ZERO-MASS-LIMIT APPROACH TO KINEMATICS AND VENEZIANO PARAMETERIZATION FOR PHOTON AMPLITUDES

Richard C. Brower*

The covariant photon amplitudes are proved to be the smooth limit of helicity amplitudes for a massive vector boson. This proof provides a rigorous basis for the zero-mass-limit technique,[1] and demonstrates its equivalence to on-mass-shell gauge invariance. The applications of the zero-mass-limit technique to kinematics, Regge expansion, and Veneziano parameterization which have been given provide a natural introduction to papers[2,3] on vector currents and current algebra.

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*Physics Department, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139.
1. Richard C. Brower, The Zero-Mass-Limit Approach to Kinematics and the Veneziano Parameterization of Photonic Amplitudes (Ph. D. thesis), Phys. Rev. (to be published).
2. Richard C. Brower and J. H. Weis, Vector Currents and Current Algebra. I. Duality and Zero-Width Models, Phys. Rev. (to be published).
3. Richard C. Brower and J. H. Weis, Vector Currents and Current Algebra. II. An N-Point Beta-Function Model, Phys. Rev. (to be published).

EXPERIMENTAL LIMITS ON THE PHOTON MASS*

Alfred S. Goldhaber†

As part of preparation of a review of this subject, the significance of long-period magnetic waves, and of pulsar waves, in obtaining a dynamic photon mass limit has been studied. The former turn out to be equivalent to static magnetic results, though less accurate. The pulsar waves yield the best dynamic limit, about four orders of magnitude worse than the static limit.

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*Work performed in collaboration with Dr. Michael Martin Nieto, Niels Bohr Institute, Copenhagen, Denmark.
†Institute for Theoretical Physics, State University of New York, Stony Brook, New York 11790.

III. PLASMA AND ATOMIC PHYSICS

EXCITATION OF A HEAVILY IONIZED ATOM

Mehdi Golshani

In the limit of applicability of the classical theory of elastic scattering, the eikonal approximation to the Coulomb-Born amplitude can be reduced to a one-dimensional path integral. This turns out to be valid for heavily ionized atoms. The path integral, in turn, can be reduced, to a good approximation, to a sum over integrals which can be done analytically.

REARRANGEMENT COLLISIONS IN THE (H^+, He) SYSTEM*

K. M. Watson

This work is in progress. The eikonal approximation is developed for the discussion of rearrangement collisions. Specific calculations will be made for the (H^+, He) system.

*Work performed in collaboration with Dr. J.C. Y. Chen, and Dr. C. S. Wang, Department of Physics, University of California–San Diego, La Jolla.

ELECTRONIC TRANSITIONS IN SLOW COLLISIONS OF ATOMS AND MOLECULES. III.*

K. M. Watson

Glory and rainbow scattering in the (He^+, He) system are studied. The eikonal approximation by Chen and Watson is used.[1]

*Work performed in collaboration with Dr. J. C. Y. Chen and Dr. C. S. Wang, Department of Physics, University of California–San Diego, La Jolla.

1. Joseph C. Y. Chen and K. M. Watson, Electronic Transitions in Slow Collisions of Atoms and Molecules. II. Calculations of Wave Functions and Green's Functions in the Eikonal Approximation, Phys. Rev. (to be published).

GREEN'S FUNCTION THEORY OF DIELECTRIC FUNCTIONS

Michael J. Smith

A many-body quantum calculation of the longitudinal and transverse dielectric functions is being made through the use of double-time temperature-dependent retarded Green's functions. The model is an isotropic plasma in which the ions form a uniform, positive background. The purpose is to identify the quantum corrections to these dielectric functions.

LINEAR RESPONSE FUNCTION FOR A FULLY IONIZED GAS

E. E. Ganfield* and Charles Ray Smith*

A temperature- and time-dependent theory is being developed for the density-density correlation function for a multicomponent, fully ionized gas in thermal equilibrium. The theory is to be used to calculate corrections to the linear response function for the pair-Hamiltonian approximation.

*Supported by Associated Western Universities and Atomic Energy Commission.

MASTER-GRAPH EXPANSION FOR THE ONE-PARTICLE GREEN'S FUNCTION FOR A MANY-BODY SYSTEM*

Charles Ray Smith†

The master-graph self-energy analysis of quantum statistics has been developed for the usual Green's function formulation of quantum statistics. This will allow a long-overdue comparison of the Mohling master-graph theory[1] with other formulations of quantum statistics.

*Work performed in collaboration with Dr. I. Rama Rao, Department of Physics, Stanford University, Stanford, California.

†Supported by Associated Western Universities and Atomic Energy Commission.

1. F. Mohling, Phys. Rev. 122, 1062 (1961).

MICROSCOPIC THEORY OF A MULTICOMPONENT SYSTEM OF CHARGED AND NEUTRAL PARTICLES

A. General Quantum-Statistical Formulation*

Charles Ray Smith†

A theory for describing a fully ionized gas in thermal equilibrium has been formulated. The theory is first developed with a counterterm in the Hamiltonian and is next subject to a complete self-energy analysis which results in integral equations for the self-energy structures and an easy prescription for identifying counterterms to achieve mass renormalization and removal of the infrared divergence. An automatic feature of the theory is to give a quasi-particle model.

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*Work performed in collaboration with Dr. Franz Mohling, Department of Physics, University of Colorado, Boulder, Colorado.
†Supported by Associated Western Universities and Atomic Energy Commission.

B. Application To The Photon Momentum Distribution

Anup Bhowmik* and Charles Ray Smith†

The foregoing theory is being used to calculate the photon momentum distribution in a fully ionized gas in the high-temperature low-density limit. Self-energy structures are included through second order in the fine-structure constant.

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*Department of Physics, University of Wyoming, Laramie, Wyoming.
†Supported by Associated Western Universities and Atomic Energy Commission.

BACKSCATTERING OF ELECTROMAGNETIC WAVES FROM THE IONSPHERE

Yu-yun Kuo

Work is continuing on the evaluation of the ionospheric electron-electron two-particle correlation function. This is of interest because it plays an important role in the multiple scattering problem.

The evaluation of the correlation function has been based on two models: (a) one of statistical equilibrium; (b) one of a turbulent fluid. In the former case the amplitude of incoherent scattering is much smaller than that of coherent scattering. Corrections may therefore be obtained by perturbation theory. Work using the second model is still incomplete, but a much different result is expected.

THE DRIVEN FIREHOSE INSTABILITY

Blake Patterson

The steady state of a plasma in which an external mechanism drives the firehose instability is being sought. Various mechanisms, such as the adiabatic expansion of the solar wind, can produce an anisotropic velocity distribution in a magnetized plasma, supporting, in turn, the firehose instability, which grows exponentially in linear theory. Nonlinear effects must limit the waves to large but finite amplitudes, such that the reaction of the waves on the distribution function balances the mechanism driving it anisotropic.

TRANSVERSE WAVE INSTABILITY DRIVEN BY SHEAR FLOW IN AN UNMAGNETIZED PLASMA

N. Albright

The transverse wave instability in an unmagnetized plasma is purely growing. Consequently the relative phase is constant in time between different Fourier components of the wave magnetic field. Thus products like $B_k(t)\ B_\ell(t)$ do not average to zero in time. Therefore if the instability were stabilized by nonlinear effects, this state would be described by a stationary solution of coherent plasma equations, not a stationary solution of (turbulent plasma) equations averaged over some fast time scale. This stabilization would correspond to the ion gyroradius's being equal to a characteristic wavelength of the instability. (Other authors have speculated

that a turbulent plasma might stabilize when the electron gyroradius was equal to characteristic wavelength.) A numerical study of the coherent plasma equations was undertaken. Preliminary results indicate that no stabilization occurs.

PLASMA SCATTERING OF ELECTROMAGNETIC WAVES

Jerry L. Peacher* and K. M. Watson

The Doppler shift in frequency of electromagnetic waves scattered by a turbulent plasma is studied by use of the radiation transport equation.[1] The shift in frequency is determined by the time scale of the plasma fluctuations.

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1. Jerry L. Peacher and Kenneth M. Watson, Dopler Shift in Frequency in the Transport of Electromagnetic Waves Through an Underdense Plasma, J. Math. Phys. (to be published).

IV. STATISTICAL AND MANY-BODY PHYSICS

MICROSCOPIC THEORY OF SUPERFLUID HELIUM

Willy Bierter* and H. L. Morrison†

We have formulated a microscopic theory of superfluid helium in terms of observable quantities only. The natural variables for this description are the particle and current densities $\rho(\underset{\sim}{x})$ and $\underset{\sim}{J}(\underset{\sim}{x})$, respectively. Using the algebra of these local observables and the Hamiltonian, also expressed in terms of these noncanonical coordinates, one can write down the equations of motion for densities and currents and a large number of sum rules. Furthermore, expanding the above Hamiltonian to second order in the density fluctuation, we immediately obtain the Bogoliubov spectrum for the low-lying excitations (phonons). Above the phonon spectrum, the creation of quantized circulation (vortons) becomes possible. This means that the total current $\underset{\sim}{J}(\underset{\sim}{x})$ now has a transverse piece and that therefore curl $\underset{\sim}{J}(\underset{\sim}{x})$ is different from zero. From the equal-time current-current commutation relation one obtains the quantization condition for the circulation. Including the transverse piece of the total current in the original Hamiltonian, expressed in terms of $\rho(\underset{\sim}{x})$ and $\underset{\sim}{J}(\underset{\sim}{x})$, we obtain a microscopic form for the vorton interaction.

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†Lawrence Radiation Laboratory-Livermore.

NONLINEAR OPTICAL ABSORPTION IN IONIC CRYSTALS: A GREEN'S FUNCTION METHOD

Charlie Harper*

A field-theoretical approach to problems in solid-state physics was employed to calculate the $\mu\nu$ element of the complex dielectric susceptibility tensor, $X_{\mu\nu}(\omega)$, for ionic crystals in the linear and nonlinear approximations. The essential problem was that of calculating the response of a physical system of interacting particles to a perturbing field. (In this particular case, the applied perturbing field was an electric field.)

In linear approximation, the absorption coefficient, $\alpha_{\mu\nu}(\omega)$, was expressed in terms of the Fourier transform of the two-time temperature-dependent Green's function.[1,2] That is to say,

$$\alpha_{\mu\nu}(\omega) = 4\pi \frac{\omega}{c} \operatorname{Im} X_{\mu\nu}(\omega) \qquad (1)$$

and

$$X_{\mu\nu}(\omega) = -2\pi \langle\langle M_\mu | M_\nu \rangle\rangle_{E=\omega+i\epsilon}, \qquad (2)$$

where Im indicates imaginary part, $\langle\langle \cdots | \cdots \rangle\rangle_{E=\omega+i\epsilon}$ indicates Fourier transform of the Green's function, and M is the electric moment. The applied field and the response are in the ν and μ directions respectively.

The nonlinear absorption coefficient was expressed in terms of the Fourier transform of a multi-time temperature-dependent Green's function.[3] Both the linear and nonlinear calculations included anharmonic terms in the Hamiltonian and second-order terms in the electric moment. That is to say,[1]

$$H_T = H_0 + H_A + H_I$$
and
$$M = M_0 + M_1. \qquad (3)$$

The results of the calculations are in agreement with measurements of optical absorption spectra of alkali halides.[4]

The general conclusions are that: (a) The method of time- and temperature-dependent Green's functions can be used to calculate transport coefficients without the use of diagrams provided a suitable decoupling procedure is employed. (b) This approach to transport problems is not very promising, since the first-order ($H_A = O = M_1$) calculation is quite lengthy and tedious. (c) The present state of the art is such that substantial advances in decoupling techniques are needed to make higher-order calculations practical. Work in the latter direction is in progress.

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2. D. N. Zubarev, Usp. Fiz. Nauk 71, 71 (1960); Translation: Soviet Physics–Uspekhi 3, 320 (1960).
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INTRODUCTION TO THE DENSITY MATRIX CONCEPT

Charlie Harper*

Considerable use is made in the literature of the density matrix concept. Although there are two different approaches (statistical and quantum mechanical) in addition to the operational and reduced usages of the density matrix, most authors fail to clearly specify their particular density matrix formulism. Hence, we have undertaken the task of clearly developing the density matrix concept starting from the classical density-distribution function.

An appropriate example problem, which involves presenting a general introduction of the theory of time-temperature-dependent Green's functions, is included. This review is at a level that is useful to students. A paper is in preparation.

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ON RELATIVISTIC STATISTICAL THERMODYNAMICS: AN IRREVERSIBLE APPROACH

Charlie Harper*

Planck[1] and Einstein[2] formulated the transformation laws for thermodynamic quantities shortly after the announcement of special relativity. These well-known transformations appear in the classical textbooks on special relativity and were not seriously criticized until 1963 by H. Ott.[3] Since 1963, many papers have been published on this subject. A comprehensive review of this controversy was given by R. Balescu[4] in 1968.

The essential problem is to determine a unique transformation law for the concept of heat. Equilibrium statistical mechanics is not sufficient for this analysis. Hence, we are extending the investigation to cover nonequilibrium processes.

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1. M. Planck, Ann. Physik 76, 1 (1908); Berliner Berichte (1907) 542.
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V. ACCELERATOR THEORY

ELECTRON RING ACCELERATOR DEVELOPMENT

Within the last year and a half, the Laboratory has mounted a large program for the development of electron-ring accelerators (ERA). Members of the Theoretical Physics Division have played an important role in this project and, at present, all the theoretical work on accelerators is connected with the ERA program. Much of it is covered in the accompanying abstracts.

In the last 6 months the primary effort has been devoted to assisting the final design studies for the Compressor-III device, participating in the experimental program at the Livermore Laboratory, assisting in the interpretation of the experimental results, and contributing to plans for the next experimental period in November. The basic tools for this work are described in the abstract by Laslett and Luccio. The "everyday" contributions of the accelerator theorists to the ERA Compressor III program are not recorded in any accompanying abstract, but were--nevertheless--of great significance to the project, and represent a large fraction of the theorists' effort.

The use of image-field focusing is a vital ingredient of the ERA, as it is presently conceived. The abstracts by Laslett and by Perkins and Laslett are concerned with this subject.

Stability of electron rings--the very heart of a successful ERA--is a continuing subject for theoretical attention. The abstracts by Garren, Laslett, and Morse and by Harper are addressed to aspects of this problem.

Electron rings of very high intensity and small dimensions are required to achieve the advantage of an ERA, namely, the compact size of the accelerator. An electron injector is now under construction, in Berkeley, which it is hoped will produce rings of higher quality than it has been possible to achieve with the Astron injector. The abstract by Garren describes theoretical work important in the design of the new electron injector.

Electron ring accelerators are examples of collective field accelerators, and consequently there is a continuing interest in this general class of devices. The two abstracts by Sessler are devoted to developments in this (relatively new) area of research.

COMPUTATION WORK SUPPORTING THE ELECTRON RING COMPRESSOR-III EXPERIMENTS

L. J. Laslett and A. V. Luccio*

Computer software and a teletype link to the LRL CDC-6600 were developed that permitted computations of compression, roll-out, and acceleration to be made at Livermore during the course of the Compressor-III experiments. Such an on-line computational capability not only provides a very convenient flexibility for the study of compression and extraction dynamics, but has proven exceedingly valuable in helping to plan and to interpret experiments in progress. This theoretical and computational work has involved, in addition to what was done by A. M. Sessler, A. A. Garren, and John Hauptman, the invaluable assistance of Mrs. Barbara Levine, Robert Healy, and John Colonias of the Mathematics and Computing Division.

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*On leave of absence from the University of Milan, Italy.

ELECTROSTATIC AND MAGNETOSTATIC IMAGE-FIELD COEFFICIENTS

L. Jackson Laslett

The derivation of image-field coefficients has been sketched and results presented[1] for a particle beam centrally located within closed (elliptical or rectangular) "picture-frame" boundaries. Image-field coefficients have also been given for structures that might usefully

be added to a synchrotron to modify the frequencies of incoherent betatron oscillations.

1. L. Jackson Laslett, Electrostatic and Magnetostatic Image-Field Coefficients (UCRL-18892, Aug. 1969), to be published in the Proceedings of the VII International Conference on High Energy Particle Accelerators.

NUMERICAL SIMULATION OF ELECTRON RINGS

A. A. Garren, L. J. Laslett, and R. Morse*

Computational techniques developed at Los Alamos for the study of collective phenomena that occur in plasma devices are being applied to a study of the dynamical behavior of electron rings.

*Los Alamos Scientific Laboratory, Los Alamos, New Mexico.

OSCILLATIONS IN A FINITE MAGNETICALLY CONFINED COLLISIONLESS ELECTRON GAS

Charlie Harper*

The Landau and Van Kampen methods of solving the Vlasov-Maxwell system of equations enable one to investigate small disturbances (oscillations) in an infinite plasma. The development of a technique for studying disturbances in a finite plasma is in progress.

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ION FOCUSING AND IMAGE FOCUSING DURING EXTRACTION OF AN ELECTRON RING

W. A. Perkins and L. J. Laslett

In an Electron Ring Accelerator (ERA) the electron ring is formed in a region of weak focusing ($n \approx 0.1$). During extraction the electron ring moves to a region in which no axial focusing is provided by the external magnetic field ($n \approx 0$). To hold the ring together axially in the $n \approx 0$ field region, another method of focusing must be provided. Also during extraction growth in oscillation amplitude (which could be caused by crossing the radial integral resonance) must be kept small. Two procedures previously proposed to overcome these difficulties are: (a) The radial integral resonance is traversed rapidly (< 100 nsec) by use of an n-shifter coil. The ring is held together axially in the $n \approx 0$ field region by ion focusing or Bennett pinch. (b) The radial tune is held below 1 (the resonance is not crossed) during extraction by the use of one or more image cylinders. Image cylinders also provide axial focusing. The cylinder must be constructed of dielectric or slotted metal so that it has electric images with small or vanishing magnetic images. Some of the constraints involved in using either (a) or (b) with ring parameters similar to those of the Berkeley ERA experiment[1] are discussed.

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THIN-LENS OPTICS WITH SPACE CHARGE*

A. A. Garren

The beam-envelope theory of Kapchinskij and Vladimirskij is applied to the case of a circular drifting relativistic beam focused by thin lenses. The envelope equation is put into dimensionless form and integrated numerically, yielding a family of envelope curves that describe beams of any momentum, emittance, and intensity. From these curves the minimum beam radius for a given lens spacing may be determined, as well as the corresponding lens strength.

*A. A. Garren, Thin Lens Optics with Space Charge (UCRL-19313, Aug. 1969), to be published in the Proceedings of the VII International Conference on High Energy Particle Accelerators.

COLLECTIVE FIELD ACCELERATION*

A. M. Sessler

Diverse methods proposed for the acceleration of particles by means of collective fields are reviewed. A survey is made of the various currently active experimental programs devoted to investigating collective acceleration; and the present status of the research is briefly noted.

*A. M. Sessler, Collective Field Acceleration (UCRL-19242, July 1969), to be published in the Proceedings of the VII International Conference on High Energy Particle Accelerators.

ACCELERATION OF PARTICLES BY COLLECTIVE FIELDS. I.*

A. M. Sessler

The recent observations[1,2] of ions accelerated by intense electron streams are noted and discussed in some detail.

*Andrew M. Sessler, Acceleration of Particles by Collective Fields. I (UCRL-19223, June 1969), Comments Nucl. Particle Phys., to be published.
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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-inch 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 University of Wisconsin and at Purdue, Johns-Hopkins, and Duke Universities. Numerous results from this experiment have been published. In late 1964, an additional 110 000 pictures of π^- incident at five different momenta from 0.910 to 1.030 GeV/c were taken for analysis at Berkeley.

Hyperon Production and Decay

The process $\pi^- + p \rightarrow \Lambda + K^0$ has been studied at incident beam momenta of 944, 966, 986, 991, 1006, and 1170 MeV/c. Differential and total cross sections and polarizations have been obtained. A partial-wave analysis incorporating previously reported data at 1030 MeV/c has been completed. The results have been reported.[1]

Radiative Pion Production

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

Tridents

We have measured 550 electron- and positron-induced tridents in a hydrogen bubble chamber. No results are yet available.

Six-Pronged Events

We have measured about 30 six-pronged events produced in $\pi^{\pm}p$ interactions around 1 GeV/c. The analysis is still in a preliminary stage.

1. Joseph Cecil Doyle, Study of $\pi^- + p \rightarrow \Lambda + K^0$ from 944 MeV/c to 1170 MeV/c (Ph. D. Thesis), UCRL-18139, Oct. 1969.

B. K63 EXPERIMENT

An exposure of the 72-inch 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

A systematic study of production and decay of Ξ^- and Ξ^0 has been undertaken. The present effort is concentrated on a partial-wave analysis of the $K^-p \rightarrow K^+\Xi^-$, $K^0\Xi^0$, and $K^-n \rightarrow K^0\Xi^-$ reactions from threshold to 2.7 GeV/c. The data can be understood in terms of I = 0 baryon exchange with small but important contributions from I = 1 baryon exchange and direct-channel resonance production.

The baryon exchange partial waves move in counterclockwise circles in the Argand diagram, suggesting that they may have a "dual" interpretation as resonances.

Reaction $K^-p \to \bar{K}^0 n$ and $K^-p \to \Lambda\pi^0$

Stanley M. Flatté, Angela Barbaro-Galtieri, Robert D. Tripp, and Charles G. Wohl

Data analysis, including production-angle distributions, polarization, and total cross sections, has been completed at six incident K^- momenta: 1.7, 2.1, 2.47, 2.59, 2.64, and 2.73 GeV/c.

Resonance Production in the Reaction $K^-p \to \Sigma\pi\pi$, $\Sigma\pi\pi\pi$

Phillippe Eberhard, Jerome H. Friedman, Morris Pripstein, Ronald R. Ross, and R. Estes

As part of an extensive study of the reactions $K^-p \to \Sigma^{\pm}\pi^{\mp}\pi^{0}$ and $K^-p \to \Sigma^{\pm}\pi^{\mp}\pi^{+}\pi^{-}$ around 2.6 GeV/c, we are now analyzing the production of the $\Sigma(1915)$ and $\Sigma(2030)$ resonances in these reactions. Since the signal-to-background ratio is small for each of these resonances, the analysis has, by necessity, been devoted in large part to studying the behavior of the background. This portion of the analysis will be completed in the near future, and shortly thereafter we should have results for publication concerning properties of these resonances. This study will provide a significant measurement of the decay branching ratios of these resonances into the $\Sigma\pi$, $\Lambda(1405)\pi$, and $\Sigma\pi\pi$ modes. At present a compilation of the world data by the Berkeley Particle Data Group yields little or no information about these various decay modes.

Our experimental results should provide a meaningful comparison with the theoretical predictions of SU(3) concerning these branching ratios.

K^- Interactions in Deuterium

Angela Barbaro-Galtieri, Maxine Matison, and Alan Rittenberg

The deuterium film of path length 5 events per μ equally divided between 2.11 and 2.6 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 negative. 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. Assuming one-pion exchange in the reaction $K^-p \to K^-\pi^-\Delta^{++}$, we have set an upper limit of 4 mb for the $T = 3/2$ $K\pi$ cross section near threshold. Results will be submitted for publication shortly.

C. K65 EXPERIMENT

During the period from August 1965 to October 1967, the 25-inch hydrogen bubble chamber was exposed to a K^- beam of about 400 MeV/c. Rougly 1.4 million pictures have been taken, 60 000 of which were in deuterium. The average track density was about six K^- per picture. All of the film has been scanned once, yielding 577 000 events. About 30% of the film has been scanned twice, and about 6% 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.

Study of Σ Decay Parameters

Robert D. Tripp, Frank T. Solmitz, and Roger O. Bangerter

In order to measure the decay parameters γ_+^+, γ_-^-, β_+^+, β_-^-, we have scanned and measured roughly 70% of our film for the reactions $\Sigma^\pm \rightarrow \pi^\pm n$, followed by $np \rightarrow np$. The β and γ are determined by the left-right asymmetry in the np scattering. We have analyzed about 2000 events of the above sequence of reactions and have submitted the results to the Physical Review.[1]

We have also analyzed the up-down asymmetry of about 140 000 Σ decays in order to determine the decay parameters α_+^+, α_0^+, and α_-^-.[2]

1. Roger O. Bangerter, Margaret Alston-Garnjost, Angela Barbaro-Galtieri, Lawrence K. Gershwin, Terry S. Mast, Joseph J. Murray, Frank T. Solmitz, M. Lynn Stevenson, and Robert D. Tripp, Decay Parameters for $\Sigma^\pm \rightarrow n\pi^\pm$, UCRL-19238, June 1969.
2. Roger O. Bangerter, Nonleptonic Decay of Sigma Hyperons (Ph. D. Thesis), UCRL-19244, July 1969.

Study of the Reactions $K^-p \rightarrow \Sigma^\pm\pi^\mp$

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

We are analyzing a sample of 140 000 events of the type $K^-p \rightarrow \Sigma^\pm\pi^\mp$. We have determined the angular distributions for these reactions and are working on a partial-wave 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 has been begun. 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 ($K^-p \rightarrow \bar{K}^0n$) and Elastic ($K^-p \rightarrow K^-p$) 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 is in progress.

$\Sigma^+ \rightarrow p\gamma$

Lawrence K. Gershwin

About 60 events of the $\Sigma^+ \rightarrow p\gamma$ have been found. The decay asymmetry is measured and found to be $-1.03^{+0.52}_{-0.42}$, whereas U-spin invariance would require that the asymmetry parameter be zero. The branching ratio

$\Sigma^+ \to p\gamma/\Sigma^+ \to p\pi^0$ has been measured and found to be $(2.76 \pm 0.51) \times 10^{-3}$. This work will be published in the Physical Review.[1,2]

1. Lawrence K. Gershwin, Margaret Alston-Garnjost, Roger O. Bangerter, Angela Barbaro-Galtieri, Terry S. Mast, Frank T. Solmitz, and Robert D. Tripp, Asymmetry Parameter and Branching Ratio of $\Sigma^+ \to p\gamma$, UCRL-19261, July 1969.
2. Lawrence K. Gershwin, Asymmetry Parameters in $\Sigma^- \to ne^-\bar{\nu}$ and $\Sigma^+ \to p\gamma$ (Ph. D. Thesis), UCRL-19246, June 1969.

Study of $K^- \to \pi^-\pi^-\pi^+$ Decay

Terry S. Mast and Lawrence K. Gershwin

A detailed analysis of 51 000 $K^- \to \pi^-\pi^-\pi^+$ decays has been completed. This sample is almost a factor of ten larger than any heretofore reported. After a thorough analysis of our detection efficiency, the events were weighted to account for the detection efficiency and the effects of final-state Coulomb interactions. The projections of the pion spectra have been fitted to simple expansions in the kinetic energies of the pions. In addition, maximum-likelihood fits to the entire Dalitz plot have been made. The decay distribution is well described by the form $1 + ay$, where y is proportional to the kinetic energy of the positive pion and a, the slope, is 0.247 ± 0.009. Comparison of this slope with that derived from a world compilation of 28 000 K^+ decays shows no evidence for CP violation. An isospin analysis of the rates and slopes of τ, τ', and $K_2^0 \to 3\pi$ decays requires, in addition to the dominant $\Delta I = 1/2$ amplitude, $\Delta I = 3/2$ amplitudes into both $I = 1$ and $I = 2$ three-pion final states. No detectable $\Delta I = 5/2$ or $\Delta I = 7/2$ amplitudes are required. A description of the experiment and the isospin analysis has been published in the Physical Review.[1]

1. Terry S. Mast, Lawrence K. Gershwin, Margaret Alston-Garnjost, Roger O. Bangerter, Angela Barbaro-Galtieri, Joseph J. Murray, Frank T. Solmitz, and Robert D. Tripp, Phys. Rev. 183, 1200 (1969).

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 $Y_0^*(1520)$.

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

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

We have analyzed about 18 000 reactions of the type $K^-p \to \bar{K}^0 n$ followed by a visible decay of the neutral K meson. After applying many selection criteria, we find 252 events in which the decay is leptonic or radiative: $K^0 \to \pi^\pm e^\mp \nu$, $\pi^\pm \mu^\mp \nu$, or $\pi^+\pi^-\gamma$. By studying the time distributions of the events, we test the $\Delta S = \Delta Q$ selection rule and also the Sachs model of CP violation. Our experiment indicates a 2.4-standard-deviation violation of the $\Delta S = \Delta Q$ rule. Results have been published.[1]

1. Bryan R. Webber, A Test of the $\Delta S = \Delta Q$ Rule in Leptonic Decays of Neutral K Mesons (Ph. D. Thesis), UCRL-19226, May 1969.

Study of $\Sigma^\pm$ Lifetimes

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

Currently there is serious disagreement among the published values of the Σ^- lifetime. We are now measuring the lifetimes for both Σ^+ and Σ^-.[1]

1. Roger O. Bangerter, Nonleptonic Decay of Sigma Hyperons (Ph. D. Thesis), UCRL-19244, July 1969.

Asymmetry Parameters for $\Sigma^- \to ne^-\bar{\nu}$

Lawrence K. Gershwin and Robert D. Tripp

From a sample of 85 000 $\Sigma^- \to n\pi^-$ decays we have found 53 examples of $\Sigma^- \to ne\bar{\nu}$, and 8 of $\Sigma^- \to n\mu\bar{\nu}$.

These leptonic Σ^- decays were analyzed to measure the correlation between the Σ^- polarization and the direction of the charged lepton, as described by the lepton distribution $(1+\alpha P_\Sigma \cos\theta)$. The asymmetry parameter α for the electron events was found to be $\alpha = -0.26 \pm 0.37$. The asymmetry parameter is related to g_A/g_V, the ratio of the axial-vector to vector weak coupling constants. We found $g_A/g_V = 0.19^{+0.20}_{-0.17}$ for the combined electron and muon events. This value is in reasonable agreement with the prediction of the Cabibbo theory when a fit is performed with presently published data for baryon leptonic decays.[1]

1. Lawrence K. Gershwin, Margaret Alston-Garnjost, Roger O. Bangerter, Angela Barbaro-Galtieri, Terry S. Mast, Frank T. Solmitz, and Robert D. Tripp, Asymmetry Parameter and Branching Ratio of $\Sigma^+ \to p\gamma$, UCRL-19261, July 1969.

D. π66 EXPERIMENT

Between February and August 1966, 665 000 pictures were taken of π^+ mesons incident on deuterium in the 72-inch 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 essentially 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 are now being investigated. In the reaction $\pi^+n \to K^0Y^{*+}$, we have observed a forward peaking which cannot be explained by the usual one-meson-exchange model without "exotic" mesons. We have analyzed data from other LRL experiments, and have noted similar "forbidden" forward peaks in several related reactions.[1]

1. Philip M. Dauber, Paul L. Hoch, Robert J. Manning, Daniel M. Siegel, Maris A. Abolins, and Gerald A. Smith, Phys. Letters 29B, 609 (1969).

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

Orin I. Dahl, Jerry Danburg,* Donald Davies,† Donald H. Miller, and Robert Rader

The analysis of the four-prong events has now been completed.[1] The data on eta production have been published,[2] and our analysis of the strange-particle events has also been published.[3] The 3500 fitted five- and six-prong events have produced (a) 2290 $pp\pi^+\pi^+\pi^-\pi^-$ events, (b) 853 $pp\pi^+\pi^+\pi^-\pi^-\pi^0$ (or $pp\pi^+\pi^+\pi^-\pi^-\gamma$) and (c) 230 $pn\pi^+\pi^+\pi^+\pi^-\pi^-$ events. Production of η' is observed in (b), and has been reported at the APS Meeting in Washington, D. C., in May 1969. Production of $\pi^+\pi^-\eta$ and $\pi^+\pi^-\omega$ are also observed in reaction (b). Some 16 000 four-prong events fitting $(n)p\pi^+\pi^+\pi^-$ were used to publish a refutation of an I = 5/2 baryon resonance.[4]

*Brookhaven National Laboratories.

†Physics Department, University of California-Los Angeles.

1. Jerome Samuel Danburg, A Study of the Reaction $\pi^+d \to (p)p\pi^+\pi^-\pi^0$ at Incident Pion Momenta Between 1.1 and 2.4 BeV/c (Ph. D. Thesis), UCRL-19275, July 1969.
2. J. S. Danburg, M. A. Abolins, R. C. Brower, O. I. Dahl, D. W. Davies, P. L. Hoch, J. Kirz, D. H. Miller, and R. K. Rader, Phys. Letters 30B, 270 (1969).

3. Donald Wayne Davies, Strange Particle Production in π^+d Interactions from 1.1 to 2.4 GeV/c (Ph. D. Thesis), UCRL-19263, July 1969.
4. Jerome S. Danburg, Donald W. Davies, Orin I. Dahl, Paul L. Hoch, Janos Kirz, Donald H. Miller, Robert K. Rader, Maris A. Abolins, Thalis Delikaris, and Gerald A. Smith, Phys. Rev. Letters 23, 41 (1969).

E. BP66 EXPERIMENT

Jared A. Anderson* and Dennis B. Smith

A 72 000-picture proton exposure was made in the Brookhaven National Laboratory 80-inch 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 nearly all 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. Results have been published.[1]

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.

*Space Sciences Laboratory, Berkeley, California.

1. Dennis B. Smith, Robert J. Sprafka, and Jared A. Anderson, Phys. Rev. Letters 23, 1064 (1969).

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, and 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.

G. P65 EXPERIMENT

An exposure of the 72-inch 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 tested Krisch's model of nucleon structure in which pions, kaons, and antinucleons are produced from different regions of the nucleon. Shapes of $p_\perp^2$ distributions for pure inelastic pion and kaon events have been compared. We find these shapes are inconsistent with such a model. A paper on this subject is being written.[1]

*Michigan State University, East Lansing, Michigan.

1. M. A. Abolins, M. Ma, G. A. Smith,

E. Gellert, and A. B. Wicklund, Evidence Against Different Interaction Radii for Pion and Kaon Production in Proton-Proton Collisions, in preparation.

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

Eugene Gellert and Gerald A. Smith*

We have studied the 3π system in $pp \rightarrow pp\,\pi^+\pi^-\pi^0$ at 6.6 GeV/c. Both $\eta(549)$ and $\omega(783)$ production are observed. We determine the cross sections to be $29\pm9\,\mu b$ for η production and $180\pm23\,\mu b$ for ω production. The $pp\omega$ events have been assigned separately to the six possible multiperipheral diagrams on the basis of criteria in the four-momentum transfers and c.m. longitudinal momenta, respectively.[1] A further analysis involving double Regge exchange will also be performed.

A comprehensive article on all pp nonstrange interaction is in preparation and will be submitted to Phys. Rev.

*Michigan State University, East Lansing, Michigan.

1. E. Colton and E. Gellert, Omega Production in $pp \rightarrow pp\pi^+\pi^-\pi^0$ at 6.6 GeV/c (UCRL-19330, Oct. 1969), submitted to Phys. Rev.

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

Bernard Deler, LeRoy R. Price, Arthur H. Rosenfeld, Paul Söding,* David Herndon, Larry Miller, Ronald Longacre, David Leith,* Anthony Brody,† and Ben Shen†

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.

To our previous 300 000 two-prong events we have now added 50 000 measurements of film from Saclay. Our former events are from film from the LRL 72-inch hydrogen bubble chamber and the MURA 30-inch chamber. The LRL film is old film obtained between 1960 and 1963. The experiment at ANL ran in late 1967 and early 1968.

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 dozen N^* and Δ resonances with masses below 2000 MeV.

*DESY, Hamburg, Germany.
†Stanford Linear Accelerator Center, Stanford, California.

I. K82 EXPERIMENT

Angela Barbaro-Galtieri, Steven 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.

L Meson

The $K\pi\pi$ enhancement at 1780 MeV (the "L meson") is copiously produced in our K^+p experiment at 12 GeV/c. We show that this "meson" can be explained as a threshold enhancement in the $K_N(1420)\pi$ system. We see no evidence for this enhancement in channels other than $K_N(1420)\pi$; therefore a resonance interpretation is not required.[1]

1. A. Barbaro-Galtieri, P. Davis, S. Flatté, J. Friedman, M. Garnjost, G. Lynch, M. Matison, M. Rabin, F. Solmitz, N. Uyeda, V. Waluch, and R. Windmolders, Phys. Rev. Letters 22, 1207 (1969).

K^* Splitting

It is shown that the $K_N(1420)$ and the $K^*(890)$ in our 12-GeV/c K^+p experiment fit poorly to the double-pole structure reported for the A_2 meson. The probability that our data agree with the double-pole hypothesis is less than 1% for the $K_N(1420)$ and completely

negligible for the $K^*(890)$, although both resonances are fitted well by a Breit-Wigner shape. Our mass resolution is ±7 MeV at the $K_N(1420)$ and ± 5 MeV at the $K^*(890)$.[1]

1. P. Davis, S. Derenzo, S. Flatté, M. Garnjost, G. Lynch, and F. Solmitz, Phys. Rev. Letters 23, 1071(1969).

A_1 Production

The production of the A_1 has been reported at 12.8 GeV/c in the reaction $K^+p \to Kp(3\pi)$. It has also been reported at 9.0 GeV/c in the reactions $K^+p \to Kp(3\pi)$ and $K^+p \to Kp(4\pi)$. At 12.0 GeV/c, with five times the data of the 12.8-GeV/c experiment and three times the data of the 9.0-GeV/c experiment, we see no evidence for A_1 production in any of these reactions.[1]

1. Monroe S. Rabin, Angela Barbaro-Galtieri, Stephen E. Derenzo, Stanley M. Flatté, Jerome H. Friedman, Margaret A. Garnjost, Gerald R. Lynch, Frank T. Solmitz, Norman M. Uyeda, and Roland Windmolders, Evidence Against A_1 Production in High-Energy K+p Interactions (UCRL-19362, Oct. 1969), submitted to Phys. Rev. Letters.

Elastic K^+p Scattering

The large statistics of this experiment will enable us to determine the dependence on the four-momentum transferred of the K^+p elastic scattering cross section out to a value of $|t| \approx 1.5\ (\mathrm{GeV})^2$. Preliminary results indicate a disagreement with the only other elastic K^+p scattering experiment done at high energy, a counter experiment done in 1963 with statistics roughly comparable to ours but with biases that were probably not very well understood.

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

More than 1500 events with a visible K^0 have been found. We are currently studying the theoretical predictions of the single Regge pole exchange model in the quasi-two-body substates of this reaction as well as the predictions of the multiperipheral model for the nonresonant substates.

Virtual Scattering

The reaction $K^+p \to K^+\pi^-\pi^+p$, of which we have 28 000 events, is being used to study virtual π^+p and $K^+\pi^-$ elastic scattering. Comparison with various theories of off-mass-shell scattering is being made.

$K^+p \to V\,Pp$

The reactions $K^+p \to K^+\omega p$, $K^+\phi p$, $K^+\rho p$, and $K^*\pi p$ are being compared in an attempt to illuminate the relationships expected from SU(3).

$K^*\pi p$

The reactions $K^+p \to K^{*0}_{1/2}(892)\,\pi^+p$ and $K^+p \to K^*_{1/2}(1420)\,\pi^+p$ are being studied at 12.0 GeV/c. One-pion exchange appears to dominate these reactions for all values of π^+p invariant mass. The invariant-mass and decay-angle distributions of the π^+p system are well approximated by real π^+p elastic scattering for both reactions. Various models of one-pion exchange are being applied to the data to test their validity. Special attention is being paid to high π^+p invariant masses, for which the $K^*\pi$ invariant-mass distributions exhibit very striking threshold enhancements corresponding to the Q enhancement in the first reaction or the L enhancement in the second.

ϕ Production

We observe more than 300 events of the type $K^+p \to K^+p\,\phi$, $\phi \to K^+K^-$, and are in the process of measuring the branching ratio of the ϕ into $\pi^+\pi^-\pi^0$. Preliminary analysis indicates that our value for this branching ratio

will be consistent with zero and in disagreement with the world average as quoted by the Particle Data Group.

J. π82 EXPERIMENT

Angela Barbaro-Galtieri, Steven 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 82-inch hydrogen bubble chamber was taken in the first half of 1969. More than three quarters of the film has been scanned for all events except two-prongs, and about 20% of the film has been measured. Studies on this film will include analysis of the A_2 splitting, including $\rho\pi$, $K\bar{K}$, and $\eta\pi$ decay modes; the $f_0 \rightarrow K\bar{K}$ branching ratio; and the $\pi\pi$-$\pi\omega$ amplitude.

K. BACKSCATTERED LASER BEAM AT SLAC

Development of the Beam

Kenneth Moffeit, William Podolsky, Monroe Rabin, Roger Gearhart, Paul Klein, Joseph Murray,* and Charles Sinclair†

A unique photon beam[1] has been developed and used with the SLAC 82-inch hydrogen bubble chamber. This variable high-energy beam is 90% polarized (linear or circular) and virtually monochromatic. It is generated by backscattering 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.

Tests have been carried out which indicate that it should be possible to extend the beam energy to 10 GeV by frequency-doubling the ruby laser light and still have enough flux for bubble chamber experiments. A bubble chamber run using the new frequency-doubled laser output is scheduled for early December.

*Stanford Linear Accelerator Center, Palo Alto, California.
†Tufts University, Medford, Massachusetts.
1. Charles K. Sinclair, Joseph J. Murray, Paul R. Klein, and Monroe Rabin, Bull. Am. Phys. Soc. (II) 14, 241 (1969).

Photoproduction Experiments

Kenneth Moffeit, Richard Milburn*
William Podolsky, Monroe Rabin,
Arthur Rosenfeld, and Roland Windmolders†
(with experimenters from SLAC,
Tufts University, and U. C. -Berkeley)

The LRL–SLAC–Tufts–UC-B collaboration has taken 825 000 pictures in the SLAC 82-inch bubble chamber with the backscattered laser beam. The exposures were:

hydrogen:

5 GeV, 460 000 pictures (140 events/μb);
3 GeV, 300 000 pictures (90 events/μb);
1.5 GeV, 20 000 pictures;

deuterium:

0.8, 3, 5, 6.5 GeV, 50 000 pictures.

The scanning and preliminary analysis of the hydrogen film is almost complete. Total cross-section results, based on a selected sample of the data, have already been published.[1]

The polarization of the incident photon beam allows us to separate Pomeron exchange (via the vector dominance model) from other particle exchanges. We expect to have final results in the very near future on vector meson photoproduction.

*Visiting from Tufts University.
†Visiting from LIBHE, Brussels, Belgium.
1. J. Ballam, G. B. Chadwick, R. Gearhart, Z. G. T. Guiragossian, P. R. Klein, A. Levy, M. Menke, J. J. Murray, P. Seyboth, G. Wolf, C. K. Sinclair, H. H. Bingham, W. B. Fretter, K. C. Moffeit, W. J. Podolsky, M. S. Rabin, A. H. Rosenfeld, and R. Windmolders, Phys. Rev. Letters 23, 498 (1969).

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 are between 7 and 8 radiation lengths thick, and form 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 is large.

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

We are presently scanning and measuring the data on the spark chamber pictures, using the automatic SASS scanning and measuring device. In addition, a portion of the data is being scanned by a team of scanning personnel. Preliminary results, based on about 20% of the data, have been reported.[1]

1. T. B. Risser et al., A High-Statistics Study of the Neutral Decay Modes of the η Meson, Bull. Am. Phys. Soc. 14, 840 (1969).

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 both 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 lab 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 by using the SASS device, with a portion of the data also being scanned by our scanning personnel. Preliminary results, based on about 10% of the data, have been reported.[1]

1. R. B. Chaffee et al., A Search for the Decay $N^* \rightarrow n\eta$ in the 1680-MeV Region, Bull. Am. Phys. Soc. 14, 840 (1969).

Neutral Diboson Experiment

With the same personnel and much of the same equipment as in the preceding spark-

chamber experiments, we have set up 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. A completely different beam from the one used in the previous experiments has been designed. 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.

We have been collecting data since the end of October 1969, and to date we have already accumulated about 10 000 events, which represents about 25% of our goal of 40 000 events.

B. DEUTERON MISSING-MASS EXPERIMENT

Maris A. Abolins,* Gerald A. Smith,* Lawrence H. Smith,† and A. Barry Wicklund

The taking of data for an experiment to measure the missing-mass spectrum associated with deuteron production in p-p collisions at 3.8, 4.5, and 6.2 GeV/c incident momenta was completed in September 1968. These data have been almost completely analyzed. The deuterons are produced at 180 deg in the c.m. system and are identified by means of a Cerenkov counter and time-of-flight criteria. They are momentum-analyzed by six magnetostrictive spark chambers. An upper limit of 0.05 μb/sr can be placed on the possible production of the "δ(963)" at each energy, provided the width is narrow, as reported by the Saclay and CERN missing-mass experiments. An article describing these results is being prepared for Phys. Rev. Letters, which will include subsequent studies of systematic biases; these enable us to report also on possible wide mass enhancements associated with the strong interactions.

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III. EXPERIMENTATION USING COSMIC RAYS

HIGH-ALTITUDE PARTICLE PHYSICS AND COSMIC-RAY EXPERIMENTAL FACILITY

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

This program, led by Luis W. Alvarez, is funded by NASA, through a contract with the Space Sciences Laboratory of the University of California. The above-named Lawrence Radiation Laboratory and Space Sciences Laboratory staff members are contributing to the project, together with a group of physicists at the NASA Manned Spacecraft Center at Houston. Because this program is currently benefiting from the availability of LRL facilities and working space, the following account is presented here.

The present immediate objective of this program is the development and construction of the Small Superconducting Magnet (SSCM) gondola, which will be used to study the spectra of cosmic-ray particles. The basic SSCM gondola system, which will be common to several planned experiments, consists of two wide-angle particle telescopes, each utilizing one side of a superconducting coil as a momentum spectrometer. Optical spark chambers, triggered by a set of scintillation counters, are used for the determination of the particle trajectory. The entire system is contained within an 8-foot-diameter pressurized sphere. With a total gondola weight of approximately 3300 lb, we expect to fly at altitudes up to 120 000 feet for 10 to 20 hours, using a 20-million-ft^3 single-cell polyethylene balloon.

The first experiment will be measurement of the energy spectrum of individual high-Z elements ($3 \leq Z \leq 30$) in the energy range

from 5 to 50 GeV/nucleon. The charge determination will be made by pulse-height analysis on a set of high-Z detectors, including cesium iodide crystals and plastic scintillators. This detector configuration (denoted as SSCM-1), with very minor or no modifications, is also suitable for several other experiments planned for subsequent flights. These include a high-statistics helium momentum spectrum, a high-statistics proton momentum spectrum, and an antimatter survey.

The SSCM-1 gondola has been assembled, and is in the final stages of testing. The high-Z cesium iodide counters have been extensively tested at a beam at the Bevatron. The planned launch date for the first flight is in December 1969 from Chico, California. This flight will use a 10-million-ft^3 balloon, and fly to an altitude of approximately 108 000 feet. The second flight will use the same gondola as the first one, and will go to 120 000 feet, using a 20-million-ft^3 balloon.

In addition, some time has been spent in the planning and design of the SSCM-2 gondola configuration, which could involve one or more of the following experiments: measurement of the electron and positron spectra, measurement of the isotope composition of the cosmic rays, and detection of γ-ray sources in the galaxy.

Long-range plans for this program necessarily center on satellite experiments, and some time has also gone into preliminary design plans for satellite configurations. Present thinking is oriented around both an instrument of size and weight comparable to SSCM for inclusion in an unmanned satellite system, and a considerably larger instrument for ultimate inclusion in a manned space station.

*Space Sciences Laboratory, University of California–Berkeley.

EMULSION SPECTROGRAPH PROGRAM

Luis W. Alvarez, Philip M. Dauber, Margaret Alston-Garnjost, Lawrence H. Smith,* M. Lynn Stevenson, and Michael A. Wahlig

A program has been undertaken to demonstrate and develop the emulsion-spectrograph technique for accurate measurement of high momenta, using spark chambers to locate the tracks. Applications at future high-energy accelerators in ground-based cosmic-ray experiments, and in balloon- or satellite-borne cosmic-ray experiments, are envisaged. We have found tracks with $\approx 99\%$ efficiency in emulsion in runs with two high-resolution optical spark chambers and a hard muon beam. A measuring stage has been constructed with 0.5×0.5 m travel, interferometric readout to $\lesssim 1\ \mu m$, and computer control. This device can be used for rapid scanning of large emulsion plates. Exploratory work has been undertaken in the construction and alignment of support structures suitable for use with large emulsion plates.

*Space Sciences Laboratory, University of California–Berkeley.

LRL–SLAC COSMIC-RAY EXPERIMENT

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

More than 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 deg zenith angle. The maximum detectable momentum has been measured and found to be greater than 2000 GeV/c, and from an analysis of 6% of the data, more than 500 events above 1000 GeV/c are expected for the whole experiment. The zenith-angle distribution

of these high-momentum events will confirm or reject the hypothesis of a new particle produced in high-energy collisions (postulated by Utah).

IV. SEARCH FOR MONOPOLES

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

The monopole detector has been used to look for Dirac monopoles in 8 kg of lunar sample brought back by the astronauts of the Apollo XI mission. No monopole was found. A paper is prepared for publication.

The sample brought back during the Apollo XII mission will be analyzed in the same manner.

V. DEVELOPMENT OF DETECTORS USING LIQUEFIED NOBLE GASES

Luis W. Alvarez, Stephen E. Derenzo, and Richard A. Muller

HIGH-SPATIAL-RESOLUTION DETECTOR

In an effort to develop a device that would record, in real time, an accurate positional measurement of the intersection of the path of a minimum-ionizing particle with a detector plane, we are investigating the electrical characteristics of liquefied noble gases.[1] Liquid argon is inexpensive, easy to handle, and after the passage of a minimum-ionizing particle provides hundreds of free electrons, even in layers as thin as 25 μ.

Our group has made the first observation[2] of the fact that when electric fields of $\approx 10^6$ volts per cm are present these free electrons avalanche, providing 0.5-V electrical signals on a 100-pF load. We have recently constructed a liquid argon wire chamber with a wire-to-wire spacing of 100 μ, only one tenth the spacing used in conventional gas-filled wire chambers, and hope to achieve a spatial accuracy of 40 μ.

Further work is planned to reduce the spacing to 20 μ and locate tracks to an accuracy within less than 10 μ.

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2. Stephen E. Derenzo, Richard A. Muller, Robert G. Smits, and Luis W. Alvarez, The Prospect of High Spatial Resolution for Counter Experiments at NAL: A New Particle Detector Using Electron Multiplication in Liquid Argon (UCRL-19254, Oct. 1969), in NAL Summer Study Report, 1969, Vol. 3.

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7. E. Colton and E. Gellert, Omega Production in $pp \rightarrow pp\pi^+\pi^-\pi^0$ at 6.6 GeV/c (UCRL-19330, Oct. 1969), submitted to Phys. Rev.

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11. P. M. Dauber, J. P. Berge, J. R. Hubbard, D. W. Merrill, and R. A. Muller, Phys. Rev. 179, 1262 (1969).

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13. Donald Wayne Davies, Strange Particle Production in π^+d Interactions from 1.1 to 2.4 GeV/c (Ph. D. Thesis), UCRL-19263, July 1969.

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15. Stephen E. Derenzo, Richard A. Muller, Robert G. Smits, and Luis W. Alvarez, The Prospect of High Spatial Resolution for Counter Experiments at NAL: A New Particle Detector Using Electron Multiplication in Liquid Argon (UCRL-19254, Oct. 1969), in NAL Summer Study Report, 1969, Vol. 3.

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17. Lawrence K. Gershwin, Asymmetry Parameters in $\Sigma^- \rightarrow ne^-\bar{\nu}$ and $\Sigma^+ \rightarrow p\gamma$ (Ph. D. Thesis), UCRL-19246, June 1969.

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VI. DATA-REDUCTION OPERATIONS

Edward H. Hoedemaker

A. EFFORT

The manpower level of the Scanning and Measuring Group averaged 55.5 full-time equivalents. This represents a drop of 17% from the previous six months, and 25% below the same period the year before.

B. SCANNING

Most of the scanning effort was concentrated on five experiments out of approximately 15 in progress during the period. In many cases, the scans were of a "nonproduction" nature, and the actual numbers of frames inspected are not indicative of the quantity of work performed. The table below reports only the hours involved (rather than the frames) for such experiments.

Several experiments were essentially completed: K63 and KD63, begun in 1963; K65, begun in 1965; and D66, π66A, and BP66, begun in 1966. No new experiments were begun.

The scanning rates of production first and second scans on the K82 and π82 experiments are, perhaps, noteworthy. The scanners on

Scanning Distribution

Experiment name (number)	Frames of first production scan	Frames of second production scan	Frames of special scan	Scan effort (h)
APE (04)				
Special scan				60.9
K72 (7)				
Ambiguities				272.2
K63 (12)				
Ambiguities				702.3
Miscellaneous				15.0
KD63 (14)				
Ambiguities				386.6
π66A (18)				
Twice failing events			146	49.4
Ambiguities			215	51.6
Conflicts			11	3.0
K65 (21)				
Special Scans			1 020	349.9
Twice failing events				261.6
Ambiguities				425.2
Training				11.4
BP66 (26)				
Ambiguities			1 823	113.9
2nd Scan		1 158		7.3
Miscellaneous				27.2
Training			377	3.9
K82 (30)				
1st scan	27 128			252.0
2nd scan		9 177		88.3
Conflicts				79.0
Accuracy checks				13.7
Miscellaneous				152.9
π82 (32)				
1st scan	528 546			3 482.7
2nd scan		47 999		319.4
Beam track scan			28 322	193.1
Conflicts				348.6
Accuracy checks				298.9
Special jobs				1 579.7
η86 (34)				
1st scan	10 892			187.9
2nd scan		2 999		63.2
Training				137.0
Accuracy checks			2 044	28.2
3rd scan			4 887	51.8
Miscellaneous			698	28.8
N^* Decay (35)				
1st scan	37 720			635.0
2nd scan		3 047		59.3
3rd scan			3 153	66.9
Training				7.6
Accuracy checks				65.5
Miscellaneous			7 247	190.7
Laser (37)				
1st scan	157 388			853.5
2nd scan		158 704		835.6
3rd scan			5 270	36.3
Ambiguities			2 427	348.9
Twice failing events				78.9
Conflicts				240.4
Accuracy checks				30.0
$e^{\pm}$ pairs				17.4
Ionization scan				47.4
Training				122.6
Miscellaneous				239.0
CR69 (42)				
1st scan	189 882			879.3
2nd scan		21 097		97.6
Accuracy checks				40.0
Nππ (43)				
1st scan	28 543			441.3
Accuracy checks				6.6
Special scans			37 881	
Group totals	980 099	244 181		153 864

K82, roughly 40% of the Scanning and Measuring Group, averaged 90 frames per hour, with an average accuracy of 93% according to fairly strict topological criteria. The same scanners have averaged 160 frames per hour on the π82 experiment, recording all event types except two-prongs. The event densities were roughly one event per frame in the 82-inch bubble chamber in both cases.

The table on the preceding page shows the distribution of the group's scanning effort by experiment and type of scan.

C. MEASURING

All together 521 452 bubble chamber events were measured this period, a rate of 1.04 million per year and a 23% decrease from the previous 6 months. The decrease was a result of several factors. (a) The MPII's were used less; (b) SRI was modified to measure 50-mm film from Saclay and was out of service for 3 weeks. (c) Both readers measured film which was relatively difficult.

Work was begun on modernizing MPIIB through the addition of a small NOVA computer. We expect more accurate measurements from this device than from conventional MP2's, and an increase in the rate by a factor of 3.

The breakdowns below show the number of events measured on each machine and the number of measurements per experiment.

Breakdown of measurements according to machine used.

	Events	Measuring hours
MPII's		
IIA	1 035	104.2
IIB	269	61.1
IIC	12 003	1763.0
IID	11 274	1355.6
All MPII's	24 581	3283.9
Spiral Readers		
SRI	265 427	2 763.8
SRII	231 444	3 527.7
Both SR's	496 871	6 291.5
All machines	521 452	9 575.4

Breakdown of measurements according to experiment.

Name (number)	Description	Number of events
Bubble chamber experiments		
APE (4)	π^-p, 72-in.	53 275
K72 (7)	k^-p, 72 in.	7
K63 (12)	k^-p, 72-in.	21
KD63 (14)	k^-n, 72-in.	706
π66A (18)	π^+n, 72-in.	504
K65 (21)	k^-p, 25-in.	18 772
BP66 (26)	pp, 80-in. BNL	8 996
K82 (30)	k^+p, 82-in.	151 804
π82 (32)	π^+n, 82-in.	69 205
Davis (33)	k^-p, 80-in.	710
Laser (37)	γp, 82-in.	18 495
CERN (39)	p^-n, 81-cm	149 775
Saclay (41)	π^-p, 80-cm	49 182
Total		521 452
Spark chamber experiments		
η86 (34)	π^-p, optic., n TOF	18 134
N^* Decay (35)	π^-p, optic., n TOF	101 204
$N\pi\pi$ (43)	π^-p, optic., n TOF	100
Total		119 438
Total for group		640 890

VII. PROGRAMMING EFFORT

PERSONNEL

Barrie Pardoe
(supervisor of Group A programmers)

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

SUMMARY

From April through November 1969 the programming group has performed the essential task of maintaining, and developing where possible, the larger programs used in the group's physics program.

Most of this work is of a routine nature and aims at making execution of the various programs more efficient; as such, it need not be described further.

New projects begun were the design and implementation of data reduction systems for both the Cosmic-Ray-Angular-Distribution experiment performed at SLAC and the Balloon Project, development of a computer-controlled Franckenstein (a conventional film-plane measuring projector), and development of an operating system for the Spiral Reader being built for the University of Tennessee. A move was also started to get the group's bubble chamber data onto the IBM 1360 photo-digital storage system.

Some of the more significant developments of individual programs are given below.

Bubble Chamber Programs

The crutch-point system on the spiral readers has been expanded to allow more information to be passed from the measuring table to the filtering program (POOH), and changes to Spiral Reader II have resulted in a more precise calibration of the optical system.

POOH now attempts to eliminate ambiguous data in regions where tracks cross, and a more sophisticated reprocessing procedure for failing events is being written which will use tracks found in one or two views to point to missing tracks.

The event-reconstruction and hypothesis-fitting program SIOUX has further been speeded up by 20% by completing the conversion to a more efficient Fortran compiler.

Spark Chamber Programs

The modified DDP24-SASS programs[1] are being used successfully by the Group A-Moyer-Helmholz collaboration, and to date 465 000 events have been measured.

The filtering of noise out of the SASS measurements has been improved in the shower-recognition program DHARMA by eliminating beam tracks and other easily identified data, and continued effort is being put into improving the handling of multishower events.

The library program SCALP for the collaboration is now operational.

For both the Cosmic-Ray-Angular-Distribution experiment and the Balloon Project, data-editing programs and reconstruction programs are being developed so that trajectories of particles through the magnetic fields can be determined from the spark chamber data. In each case the same subprogram, developed by the group to calculate the magnetic rigidity of particle trajectories, will be used.

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

General Support

The OPTIME program, for maximizing likelihood functions arising from the fitting of data to differential distributions, was generalized to permit specification of the distributions either in closed form or as a histogram.

Work on the programs for the particle data and cross-section compendium (put out as UCRL-8030 and UCRL-20000 respectively) has continued, and the programs are now operational. No major changes to these programs are contemplated; instead, a more sophisticated system is being developed to permit ready specification of data to be selected from the data banks and its display in any of several print or plot forms.

One of the Mark II Franckensteins is being converted from a manual to a computer-controlled machine, a Data General NOVA computer being used to handle data acquisition and control. The reason for the conversion is to increase the power and measuring rate of the one Franckenstein so that the remaining Franckensteins can be phased out, which will result in saving of the considerable maintenance and operating costs for those machines.

The PDP8 program to drive the granite stage to be used in measuring emulsions from the emulsion spectrograph was almost completed.

The Spiral Reader being built for the University of Tennessee will be controlled by PDP9 and PDP8 computers. The PDP4 op-

Recent Programming Notes

Note Number	Date	Author(s)	Title
P-185	March '69	William Podolsky	SLUSH--SLAC Tapes to LRL
P-186	May '69	Nancy Gould	6600 ARROW System
P-187	May '69	Max Leavitt	SASS--The SASS-System Configuration Program for the N^* and η experiments--C/E
P-188	May '69	Max Leavitt	SASS: The SASS-System Automatic Scanning Program for the N^* and and η Experiments--Flickers
P-189	July '69	Jerry Friedman	SAGE--A Las Vegas Event Generator
P-190	July '69	Stephen E. Derenzo	MINF68--A General Minimizing Routine
P-191	October '69	M. A. Garnjost	Changes to SIOUX, to Incorporate 82-inch Chamber Constants, Bubble Density Information, and Beam Averaging for the SLAC 12-GeV K^+ and 7.2-GeV π^+ Beams
P-192	October '69	L. Miller	CDC 6600 Instruction Execution Timing
P-193	October '69	W. Koellner	WRITEX--Group-A MSS Write Routine
P-194	October '69	C. O. Gimber	SCALP--Spark Chamber Analysis Library Program

erating system (OAKTREE) used to drive the group's spiral readers is being adapted to run on this configuration.

And, in relation to the group's efforts in improving the operating system and software generally available:

(a) The Berkeley Remote Facility has been expanded to provide more flexible use of remote consoles--particularly by including on-line program storage and retrieval features and matrix-manipulation routines.

(b) A move was started to record bubble chamber data on the IBM 1360 photodigital storage system. Data editing and other specialized routines are being written for this purpose.

(c) The CDC 6600 central memory loader written by this group and now in wide use by the Laboratory has been modified to provide overlay facilities and to use the random-access features of the disk devices in calling library routines.

VIII. PARTICLE DATA GROUP

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

Current Activities

This group is involved in three major activities:

1. The periodic issuance of "Reviews of Particle Properties," both annually in Reviews of Modern Physics, and as the unpublished report, UCRL-8030, printed both 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.

A few comments on each of these activities follow.

1. Particle Properties

The January 1969 edition had eight authors, six of them listed as at LRL (although two had departed during the year), two from other institutions. As the volume of data has increased, we have added two more authors, so that the January 1970 edition will have ten authors, five at LRL and five from elsewhere.

We try to judge the usefulness of this work from the frequency with which it is quoted as a reference. A count of citations in the Science Citation Index allows us to compare our review with the sum of all other reviews published each year in Reviews of Modern Physics. In the 1968 Index, citations to our 1967 Review led citations to all others:

Citations of our 1967 Review..... 266
Citations of all 34 other 1967 articles.... 243

It is not meaningful to compare our 1968 Review article with other 1968 articles by looking at the 1968 Index. The reason is that articles appearing late in the year do not have a chance to be quoted yet.

2. Particle Cross Sections

The first UCRL-20 000 was printed and mailed in November 1969. The status of the entire series is most easily summarized in the Preface to the Series, Fig. 1.

3. System Development

One of the limitations of standard computer printout is the rather small set of characters available (upper case Roman, the numerals, and a limited number of symbols). This generally prohibits the direct use of such printout, for publication purposes. In an attempt to circumvent this problem, we are beginning to develop an extended character-set system, allowing for lower case Roman, upper and lower case Greek, boldface,

PREFACE TO THE SERIES

This is the first in a new series of reports produced by the Particle Data Group. In this series we will collect and display total and differential cross sections, polarizations, mass spectra, and other similar data. Each report will cover one input channel. This one is K^+N (K^+p and K^+d). In the next few months we hope to bring out NN, π^+N, and $\bar{N}N$. Following later will be π^-N, K^-N, etc. All reports will be complete from January 1968, and will also contain selected results before that date. The reports will be updated periodically, as necessary.

At present there are seventeen physicists in the Particle Data Group who are working on one or more phases of these reports. They are:

System Development (LRL)
- Art Rosenfeld
- LeRoy Price
- Odette Benary
- Naomi Schmidt†

Encoding Data (LRL)
- Odette Benary
- LeRoy Price
- Naomi Schmidt†

K^+N Interactions (LRL)
- Odette Benary
- Roger Bland‡
- LeRoy Price
- Naomi Schmidt†
- *Charles Wohl§
- V. Henri (CERN) starting Sept.'69

K^-N Interactions (CERN)
- *Claude Bricman (below 2.5 GeV/c)
- Enzo Flaminio (above 2.5 GeV/c)

π^+N Interactions (MIT)
- *Henry Lubatti‖
- Terry Watts#
- Fred Winkelmann

π^-N Interactions
- *Tom Ferbel (BNL)
- David Miller (MIT)

NN Interactions
- Gideon Alexander (Tel-Aviv)
- Odette Benary (LRL)

$\bar{N}N$ Interactions
- Yoshio Sumi (Osaka)
- *Alan Thorndike (BNL)
- Frank Turkot (BNL)
- Toshihiro Yoshida (Kyoto)

If you have any suggestions for improving these reports, please let us know. Our address is:

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Lawrence Radiation Laboratory
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*"Chairman."

†Now at Brandeis Univ., Waltham, Massachusetts.

‡Now at Ecole Polytechnique, Paris.

§Now at RHEL, Chilton, Didcot, Berkshire.

‖Now at University of Washington, Seattle, Washington.

#Now at SLAC, Stanford, California.

Fig. 1

italic, and subscript and superscript characters, and the large number of special symbols needed for physics and mathematical formulae. Such a system consists principally of three components: (a) an input device, (b) computer programs to handle the character strings generated, and (c) an output device.

To date we have had a special keyboard built which allows for the easy typing of a large set of characters. This keyboard is interfaced to the CDC 6600 computers through one of the VISTA system cathode-ray-tube terminals. A small program that has been written permits the user of the keyboard to see on the CRT what he has typed and to do a limited amount of editing. Our intentions for the near future are to modify our data-compilation programs so that they can accept and manipulate input from this keyboard system, and then to have these programs print out their results via a photocomposing device capable of reproducing our complete character set. It is hoped that such a system will improve the readability of printout and reduce the need for expensive typesetting operations.

Particle Data Publications

1. J. Ballam et al., Production of ρ^0 Mesons by Linearly Polarized Photons at 2.8 and 4.7 GeV, SLAC Pub. -654 (also submitted to the Proceedings of the American Physical Society Meeting, Boulder, Colorado, August 1969).

2. J. Ballam et al., Total and Partial Production Cross Sections at 1.44, 2.8, and 4.7 GeV, Phys. Rev. Letters 23, 498 (1969).

3. Charles Baltay and Arthur H. Rosenfeld, Editors, Meson Spectroscopy: A Collection of Articles (W. A. Benjamin, New York, 1968).

4. A. D. Brody, D. W. G. S. Leith, B. S. Levi, B. C. Shen, D. Herndon, R. Longacre, L. Price, A. H. Rosenfeld, and P. Söding, Comparison of Phase Shift Analysis Solutions to $\pi^- p$ Scattering Data, Phys. Rev. Letters 22, 1401 (1969).

5. Particle Data Group (LeRoy R. Price, Naomi Barash-Schmidt, Odette Benary, Roger W. Bland, Arthur H. Rosenfeld, and Charles G. Wohl), A Compilation of K^+N Reactions, UCRL-20 000, K^+N, Sept. 1969. (This 235-page compilation is the first of a complete series.)

6. A. H. Rosenfeld, $\pi^- p$ Partial-Wave Analysis, presented to Lund International Conference on High Energy Physics, June 1969.

7. A. H. Rosenfeld and G. A. Snow, Elementary Particles and Interactions, American Institute of Physics Handbook, 1969, and University of Maryland Physics Technical Report 992, June 1969.

EXPERIMENTAL PHYSICS

Kenneth M. Crowe and Donald H. Miller in charge

PRECISION MEASUREMENT OF THE MUON'S MAGNETIC MOMENT

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

An improved measurement of the magnetic moment of the positive muon is currently under way at the 184-inch cyclotron. The technique consists of stopping muons in a suitable target located in a uniform, high (11 kG) magnetic field. The muon's magnetic moment precesses about the field direction, and at some time the muon decays asymmetrically into leptons. The time interval between stopping of a muon and detection of the decay positron is recorded by a digital timing system. The resulting distribution is an exponentially decaying function modulated by the muon precession. The precession frequency is extracted and compared with the precession frequency of protons in water, yielding a value of $(g/m)_{\mu^+}$ to (g/m) proton. The present uncertainty in this ratio is about 20 ppm. We expect the present experiment to yield an accuracy of less than 5 ppm.

The experiment was set up in the proton cave of the cyclotron in August. The target being investigated was located at the center of an Atlas-type magnet, which is regulated by conventional means and NMR control to ±2 ppm. The magnet was shimmed to ±5 ppm inside a 3-in. cubical volume. A muon beam of 200 MeV/c impinged on the target after passing through 2 in. of copper degrader. A stopping rate of 1800 muons per second was achieved for a 2-in. carbon target. The detection rate for electrons from muon decay was 60/sec. The background was 2%. The muon decay asymmetry was used to optimize the experimental arrangement (placement of the target, location of counters and phototube shields). The decay asymmetry was then studied in various substances, including carbon, Lucite, copper, distilled water, sodium hydroxide solutions, paramagnetic solutions, sulfur, boron carbide, boron, quartz, malononitrile, bromoform, and nitromethane.

π-π (I = 0) S-WAVE INTERACTION

Kenneth M. Crowe, Ned Dairiki, and Tin Maung*

The analysis of an experiment to study the S-wave I = 0 π-π interaction is continuing. For the reaction $\pi^- + p \rightarrow \pi^0 + \pi^0 + n$ near threshold the energy available to any final-state pion-nucleon system occurs much below the established isobar resonances. Thus, a pion-pion interaction might be expected to be a dominant feature in the final state of this reaction, and should exhibit itself in the energy distribution of the neutron.

The basic arrangement consisted of an array of spark chambers to detect the γ rays from neutral pion decays at the point of interaction (a hydrogen target), with neutron counters at the end of a flight path of 20 feet for measurement of the neutron time-of-flight spectrum. A time resolution of 1.5 nsec in the time-of-flight spectra would result in an effective-mass resolution of up to 10 MeV in the π-π mass. The experiment was performed

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in the spring of 1968 at the 184-inch synchrocyclotron in a collaborative effort with UCSD.

Data were taken at four neutron laboratory angles: 30, 35, 40, and 45 deg. The reduction of these data by constraints on the event reconstruction have resulted in 750 to 1000 good events in the two-π^0 final state for each neutron angle. Final analysis is presently in progress.

MEASUREMENT OF THE DIFFERENTIAL CROSS SECTION FOR $\pi^- p \rightarrow n\gamma$ AT 200, 320, AND 370 MeV

Anthony S. L. Parsons, Peter Truoel, Peter A. Berardo,* Roy P. Haddock,* Bernard M. K. Nefkens,* Lynn Verhey,* and Michael E. Zeller*

The analysis phase of this experiment is continuing, with emphasis on systematic effects and refinements of a simulation program. Determination of the energy-dependent cross scattering and detection efficiency of the neutron counters has been concluded and reported.[1]

Current results at 370 MeV were reported in September 1969 at the International Symposium on Electron and Photon Interaction at High Energies in Daresbury, England. Our data disagree with the SU(3) prediction that the Roper $P_{11}(1460)$ should be classified in an antidecuplet. However, the data are consistent with simple quark-model predictions of an octet classification. With the assumption of time reversibility, we agree with data for the inverse reaction.

Final analysis is in progress, and includes the determination of (a) final cross sections for the three energies above, (b) the isospin amplitudes, and (c) final cross sections for the supplementary reaction $\pi^- p \rightarrow n\pi^0$ at the same energies and angles.

*University of California–Los Angeles.

1. Anthony S. L. Parsons, Peter Truoel, Peter A. Berardo, Roy P. Haddock, Lynn Verhey, and Michael E. Zeller, A Scintillation Counter Array for Detection of High Energy Neutrons (UCRL-19259, July 1969), Nucl. Instr. Methods (to be published).

RADIATIVE CAPTURE OF STOPPED π^- MESONS ON NUCLEI

James A. Bistirlich, Kenneth M. Crowe, Anthony S. L. Parsons, and Peter Truoel

We have measured, in an experiment completed in July 1969 at the 184-inch cyclotron, the spectrum of high-energy γ rays following the capture of π^- on several light nuclei, i.e., the process $\pi^- + NCAZ) \rightarrow NCA, Z-1) + \gamma$. With the pair spectrometer we described in an earlier report we were able to accumulate 10 000 events for each of the elements ^4He, ^6Li, ^{12}C, ^{16}O, ^{24}Mg, and ^{40}Ca. In addition, the reaction $\pi^- p \rightarrow n\gamma$ with pions at rest has been studied to investigate the properties of the spectrometer. We reached an optimum resolution of 2 MeV, or 1.5% for a 130-MeV γ ray. The scanning of the spark chamber pictures has not been completed yet, but preliminary results for the carbon spectra have been presented at the New York Conference on High Energy Physics and Nuclear Structure.[1] The form of spectrum clearly supports the hypothesis that pion capture proceeds, as does muon capture, via the excitation of collective state in the residual nucleus. These are the $\Delta T = -1$ states analogous to the giant resonances seen in inelastic electron scattering and photoabsorption.

1. James A. Bistirlich, Kenneth M. Crowe, Anthony S. L. Parsons, Paul Skarek, and Peter Truoel, Gamma Spectra from Radiative Pion Capture in Carbon, in Proceedings of the Third International Conference on High Energy Physics and Nuclear Structure, New York, N. Y., September 8-13, 1969.

MEASUREMENT OF THE DIFFERENTIAL CROSS SECTION FOR $\pi^- p \rightarrow n\gamma$ BETWEEN 500 AND 875 MeV/c PION MOMENTA

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

An experiment to measure this process has been run at the Bevatron, using essentially the same equipment as the cyclotron experiment (see above). An excitation curve has been taken at $\theta_{\gamma_{c.m.}} = 90$ deg between 490 MeV/c and 875 MeV/c, in steps of about 50 MeV/c. Five-point angular distributions were taken for $45 \leq \theta_{\gamma_{c.m.}} \leq 150$ deg at 550, 600, 650, and 700 MeV/c.

The results should yield important information on the neutral radiative decay of pion-nucleon resonances in the mass region 1400 to 1850 MeV, notably the P_{11} and D_{13}. The data could, also, be used for testing the Dat-Weisskopf relation, which links pion photoproduction to pion production of ρ and ω mesons. Further, a test of time reversal (comparing with the inverse reaction $n\gamma \rightarrow \pi^- p$) could be made to about 8%. Preliminary analysis of some excitation-curve points gives good agreement with the inverse-reaction data of Neugebauer et al.[1]

We have also measured the charge-exchange process in this energy region in hopes of improving data for phase-shift analysis of pion-nucleon interactions. The neutron time-of-flight information was used for extracting these data.

*University of California — Los Angeles.

1. G. Neugebauer, W. Wales, and R. C. Wallace, Phys. Rev. 119, 1726 (1960).

NUCLEAR EMULSION GROUP

Harry H. Heckman in charge

TEMPORAL BEHAVIOR OF INNER-BELT PROTONS

Harry H. Heckman, Peter J. Lindstrom,* and George H. Nakano†

We have begun a theoretical analysis of our experimental data that pertain to solar-cycle variations in the flux of low altitude, energetic ($E \geqslant 57$ MeV), geomagnetically trapped protons. Data on the temporal behavior of the trapped protons observed since late 1962 are being interpreted in terms of the time-dependent continuity equation,

$$\frac{dN}{dt} = S - \frac{d}{dE}\left(vN\frac{dE}{dx}\right) - \rho\sigma vN,$$

where N = particle density in units $cm^{-3}MeV^{-1}$, and S = source strength in units $cm^{-3}sec^{-1}MeV^{-1}$. The second and third terms on the right are, respectively, the rate of particle loss owing to energy loss by ionization, and nuclear interactions in the residual atmosphere. Using a source function, S, that is empirically deduced from the data, we have obtained preliminary computational results indicating that:

(a) The observed temporal changes in the flux of 63-MeV protons since 1963, at altitudes $220 < \bar{h}_{min} < 450$ km, are in agreement with those expected from the solar-cycle changes in the atmosphere.

(b) The computed time history of the proton flux at 60 MeV before and after the July 1962 Starfish detonation is in excellent agreement with the observations by Filz and Holeman,[1] as well as with our post-Starfish data.

(c) For altitudes about 250 km, semiannual density changes in the atmosphere should be observable in flux changes of protons $E \lesssim 60$ MeV. That a phase difference may exist between the observed and computed semiannual changes in the proton flux is unexpected and needs to be explained.

Pitch angle diffusion, which may be an effective source strongly correlated with the atmospheric density, must now be included in the theory in order to see whether or not it can account for the altitude dependence of the source function implicated by our experimental observations.

*Space Sciences Laboratory, University of California–Berkeley.
†Lockheed Missiles and Space Company, Palo Alto.

1. R. Filz and E. Holeman, J. Geophys. Res. 70, 5807 (1965).

PARTICLE IDENTIFIER*

Harry H. Heckman and Douglas Greiner†

A first, and successful, rocket flight with this instrument was carried out on September 19, 1969. The purpose of the flight experiment was to study trapped particles at ≈ 1000 km altitudes at the geomagnetic equator. Launch site was Natal, Brazil. As described in a previous report,[1] the particle identifier is a linear array of eight silicon detectors, which provides dE/dx information as a function of range. Chi-square analysis of the pulse information allows energy determination to accuracy within less than 0.1% for the hydrogen and helium isotopes. The energy range is $30 < E < 100$ MeV/nucleon. Data tapes for this experiment have been received and the analysis of the data has begun.

*Work supported by the National Aeronautics and Space Administration.
†Space Sciences Laboratory, University of California–Berkeley.
1. Physics Division Semiannual Report, UCRL-18235, May 1968, p. 43.

MEASURING RIGIDITY SPECTRA OF HEAVY COSMIC-RAY IONS WITH USE OF A SUPERCONDUCTING MAGNET

Harry H. Heckman,
in cooperation with Robert L. Golden,
Manned Spacecraft Center, Houston,
and Clifford L. Deney,
Lockheed Electronics Company, Houston

Cosmic ray rigidities well above geomagnetic cutoff are being measured by using emulsion plates exposed in a magnetic field supplied by a 10-kG superconducting magnet. The balloon-borne apparatus, with a 50-cm^2-sr geometry factor, has twice been flown above 130 000 feet for 10 hours--from Palestine, Texas, in June and August 1969. Data obtained from the flights are being used to measure the charge composition and rigidity spectra of multiply charged nuclei. The rigidity resolution is expected to be 10% at 5 GV and 50% at 350 GV.

The magnet is a 12-in.-i.d. coil which carries 0.53×10^6 ampere-turns. The conductor is single-strand copper-clad niobium-titanium. The coil is wound as an integral part of a 25-liter helium Dewar. The Dewar's capacity allows 50 hours of magnet operation without replenishment of the helium.

The spectrometer consists of three sections:

(a) Rigidity section: Five 4×6-in. glass plates, coated on both sides with nuclear emulsion, and placed in the field 1.5 in. apart, permitting measurements of the sagitta of incident ions.

(b) Shifter section: A $4 \times 6 \times 0.25$-in. emulsion stack placed immediately below the rigidity section. This stack is shifted with respect to section (a) when the experiment reaches float altitude and again when the magnet is discharged at altitude.

(c) Target section: A $4 \times 4 \times 6$-in. emulsion stack placed beneath (b). The stack is used for charge determination and fragmentation studies.

Preliminary data from the June flight were reported at the Budapest Conference on Cosmic Rays. Scanning is now in progress on the August flight experiment.

PUBLICATIONS AND PAPERS

Articles

Harry H. Heckman and George H. Nakano, Low-Altitude Trapped Protons During Solar Minimum Period, 1962–1966, J. Geophys. Res. 74, 3575 (1969).

Harry H. Heckman, Peter J. Lindstrom, and George H. Nakano, Long-Term Behavior of Energetic Inner-Belt Protons (UCRL-19309, October 1969), presented at IAGA, Commission V, Madrid, Spain, September 1969.

Paper

Robert L. Golden, Clifford L. Deney, and Harry H. Heckman, Measurements of Cosmic-Ray Rigidity Spectra Using a Superconducting Magnet, 11th International Conference on Cosmic Rays, Budapest, Hungary, September 1969.

EXPERIMENTAL PHYSICS

Edward J. Lofgren in charge

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

Alan R. Clark, Bruce Cork,* Tom Elioff, Leroy T. Kerth, T. N. Rangaswamy, and W. A. Wenzel

Scanning and measurement on SASS (the Spark Chamber Automatic Scanning System), as well as geometric reconstruction and kinematic fitting, have been completed. The preliminary dipion invariant mass distributions include 120 000 events under the ρ^0 peak, and 30 000 under the f^0 peak. The corrections for apparatus efficiency have been compared. Fitting programs are now under way to get the final data on the mass, Treiman-Yang angle, and π-π scattering angle distributions. Limits of $\approx$ 10 μb should be set for particle production where no peaks are seen. An abstract[1] was submitted to the 1969 New York A. P. S. meeting, and some of the features of the raw data were presented at the May 1969 Argonne Conference on $\pi\pi$ and $K\pi$ Interactions.

The data taken on dikaons will be analyzed after the dipion work is complete.

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1. T. N. Rangaswamy, A. R. Clark, Bruce Cork, T. Elioff, L. T. Kerth, and W. A. Wenzel, Dipion Production at 3 to 5 BeV/c, UCRL-18603 Abstract, Nov. 1968.

NUCLEON-NUCLEON TRIPLE SCATTERING

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

Data taking, at the 184-inch cyclotron, has been completed. The apparatus worked very well for 6×10^7 triggers, and the superconducting solenoid was found to be very stable and very easy to use.

Analysis is near completion, and about 10^6 triply scattered events have survived all the tests and cuts. Polarization data on p-p scattering are in agreement with previous experiments, with similar-sized error bars.

It is hoped that the remainder of the analysis will be complete by the end of the year.

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MEASUREMENT OF THE $(K^+ \to e^+\nu)/K^+ \to \mu^+\nu)$ 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 $K^+ \to e^+\nu$. It is hoped to obtain a 5% determination of the branching ratio.

The photographs are being scanned by SASS, and computer programs for spatial reconstruction and momentum analysis have been written and largely debugged. Approximately three-fourths of the data have been scanned and measured. In the 5% of the data that has been completely analyzed, 40 Ke_2 events have been found. The resolution of the distributions appears to be ±3 MeV/c FWHM, and this will afford a clean separation of the $K \to e\nu$ mode from the other K decay modes. A determination on $K \to e\nu\gamma$ appears practical.

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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

This experiment will look for evidence of neutral leptonic currents by searching for the previously unobserved decays $K_L^0 \rightarrow \mu^+\mu^-$, $K_L^0 \rightarrow e^+e^-$, and $K_L^0 \rightarrow \mu^\pm e^\mp$. The apparatus will be able to measure the branching ratios of these decays down to $\approx 10^{-8}$; Monte Carlo calculations indicate that a branching ratio ($K_L^0 \rightarrow \mu^+\mu^-/K_L^0 \rightarrow$ all) of 10^{-8} will result in the detection of five such events in a 50-period Bevatron run.

Testing of the neutral beam with the rapid-cycling spark chambers began in July. Tests and calibration of the scintillation and Cerenkov counters in a parasitic beam were completed in August; and installation of the apparatus in the neutral beam was also finished in August.

Testing of the complete system was carried out in September and October, and some preliminary data were obtained. The PDP-9 programs have been completed, as are the CDC-6600 programs for preliminary analysis of the data.

We hope to begin taking data in November.

PUBLICATIONS AND PAPERS

1. L. T. Kerth, K. C. Leung, and Pamela Surko, Measurement of Wolfenstein Triple-Scattering Parameters, UCRL-19236, June 1969; presented at Hawaii Meeting of the American Physical Society, September 2-5, 1969.

EXPERIMENTAL PHYSICS

Burton J. Moyer and A. Carl Helmholz in charge

STUDY OF THE NEUTRAL DECAY MODE OF THE K_L^0 AND OF REGENERATION OF K_S^0

R. J. Cence,* V. Z. Peterson,* J. Wilson,* R. W. Kenney, I. Linscott, W. P. Oliver, S. Parker, and C. Rey

The preceding semiannual report contained our result for the branching ratio $(K_L^0 \to 2\pi^0)/(K_L^0 \to 3\pi^0)$, from which a value for the parameter $|\eta_{00}|^2$ was deduced. This work was published in Phys. Rev. Letters,[1] in which the result $|\eta_{00}|^2 = [14.1 \pm 1.9$ (stat.) ± 2.8 (syst.)$] \times 10^{-6}$ was given, a value implying that the superweak interaction theory (which requires 4×10^{-6} for $|\eta_{00}|^2$) would not be a correct interpretation of the processes underlying the CP-violating decay of the K_L^0 into two π^0's.

In the months since the publication further study of the data has progressed, with the goal of reducing the systematic uncertainty quoted above. Also the amount of input data contributing to a final result has been somewhat enlarged by removal of some uncertainties concerning scanning and identification that attended a portion of the spark chamber pictures. We are now working toward a full-scale article for publication, with statistical and systematic uncertainties reduced to the minimum values of which we believe the experiment is capable.

We are also now at work on the study of the regeneration of the K_S^0 by interaction of the K_L^0 in C and Be slabs. This effort will produce experimental values for the forward regeneration amplitudes at the K_L^0 momentum here employed (530 MeV/c). The Be regenerator material was placed in the beam in two different spatial distributions: (a) in a single slab, and (b) the same material in five separated slabs. This allows a distinction between the coherent bulk regeneration prominent in case (a), and the nuclear diffraction regeneration dominating case (b). Interference of the amplitude for $2\pi^0$ decay arising from the coherently regenerated K_S^0's with the $2\pi^0$ amplitude from the CP-violating K_L^0 decay will affect the observed yeild of four-shower events in case (a); and this may give us some information, though not very precise, on the relative phases of the processes involved.

The further problem of the study of the momentum dependence of the matrix element effective in the $K_L^0 \to 3\pi^0$ decay is active. Results await refinement of a partially automatic scanning and measuring process that will allow the treatment of a sufficiently large number of the six-shower events from the dominant $3\pi^0$ decay mode.

*University of Hawaii, Honolulu, Hawaii.

1. R. J. Cence, B. D. Jones, V. Z. Peterson, V. J. Stenger, J. Wilson, D. Cheng, R. D. Eandi, R. W. Kenney, I. Linscott, W. P. Oliver, S. Parker, and C. Rey, Phys. Rev. Letters 22, 1210-14 (1969).

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

Brownlee Gauld, Michael Goitein, Robert J. Cence,* Brian D. Jones,* Richard Morgado,* Vincent Z. Peterson,* Leroy Shiraishi,* David Yount,* Douglas Clarke,† David Cline,† and Robert Frommer†

At the time of the preceding semiannual

report the apparatus for study of this rare decay process was in position at the Bevatron, and the taking of data was expected to soon begin, after a brief period of final beam tuning and parameter adjustment. This hope was not fulfilled because of a failure of the several "spark-o-strictive" chambers to demonstrate the multiple-track efficiency required of them and expected from them upon the basis of bench tests during their development.

The group was forced to direct its effort to a study of these chambers over a period of the next few months in order to identify the factors affecting their efficient operation in the setting the experiment. A number of improvements were made, among them the following: (a) use of a different design of high-voltage pulser, (b) careful control of the spacing (and uniformity of spacing) of the sensing wand wires with respect to the chamber wires, (c) experimentation with the alcohol content and purity of the chamber gas, and better control of these, and (d) introduction of a He atmosphere into the region where the wand wires face the chamber wires. A system of producing one, two, or three tracks in a chamber under test was devised by multiple magnetic bending of trajectories of energetic β particles from a radioactive source so as to involve the desired number of passages through the chamber. Finally a reliable quality of operation, with adequate multiple-track efficiency, was achieved.

Concurrently with the chamber operational work, the tuning of beam conditions and the improvement (reduction) of the trigger rate proceeded. The reduction of the trigger rate involved elimination of certain accidental coincidences in counter responses by the addition of some counters to raise the order of the coincidence requirement giving the logical signal leading to a trigger.

As of the end of October the condition of the system appeared favorable for proceeding into data taking.

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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*

The past six months have been largely devoted to completing details of the data analysis and to reporting our results and experimental methods in a series of papers. See preceding Physics Division Semiannual Report. The final account of this work will be submitted in full to Physical Review shortly.

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†Tufts University, Medford, Massachusetts.

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 these experiments 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 has been completed through the running stage. It is a study of neutral final states in η decay and, we hope, will rectify the present disagreements among existing branching ratio measurements. Film analysis is currently under way. An abstract covering preliminary results was submitted to the Lund International Conference on Elementary Particles.

The second experiment is also complete through the running stage. The reactions $\pi^- p \rightarrow N^*_{1/2}(1680) \rightarrow \eta n$ and $\pi^- p \rightarrow N^*_{1/2}(1688) \rightarrow \eta n$ are being looked for in the film analysis.

There is 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 not far enough along 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 complete study of the $\pi^0\pi^0$ system in the reaction $\pi^- p \rightarrow \pi^0\pi^0 n$. It is currently under way. We have expended 20% of our allotted running time (as of Nov. 12, 1969) while collecting a number of analyzable $\pi^0\pi^0 n$ events in excess of the former world's supply.

In each experiment γ rays are detected by a five-sided cube of lead-plate spark chambers used by the Moyer-Helmholz group for the recent $K^0_L \rightarrow \pi^0\pi^0$ experiment at the Bevatron. Neutrons are detected by 20 large scintillation counters, and the spark chamber system is 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 has been tuned, and it operates as designed over a momentum range from 1.6 to 2.4 GeV/c.

*Group A, LRL.

μ^--CAPTURE NUCLEAR γ RAYS

S. N. Kaplan, R. V. Pyle, L. E. Temple, and G. F. Valby

Some further results of the analyses of γ-ray Doppler broadening following μ^- capture in ^{16}O were reported at the Third International Conference on High Energy Physics and Nuclear Structure in New York in early September 1969.[1]

Measurements of γ-ray spectra for several nuclei following μ^- capture have been made at the 184-inch cyclotron. Target materials included Al, Si, S, Ca, Co, and Ni.

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 (UCRL-19348, Sept. 1969), in Proceedings of the Third International Conference on High Energy Physics and Nuclear Structure, New York, September 1969) (to be published).

MEASUREMENT OF $n + p \rightarrow \gamma + d$ ANGULAR DISTRIBUTION AS A DIRECT TEST OF TIME REVERSAL IN THE ELECTROMAGNETIC INTERACTION

David Cheng, Victor Perez-Mendez, and Johnie M. Sperinde, Jerome A. Helland,* Bryce L. Schrock,* Roy P. Haddock,* and J. Detoeuf* Michael J. Longo,† S. Wilson,† and K. K. Young†

The angular distribution on the reaction $n + p \rightarrow \gamma + d$ was measured at incident neutron energies spanning the $N^*(1238)$ resonance, for the purpose of comparing this distribution to that of the inverse reaction $\gamma + d \rightarrow n + p$. Such a comparison is a direct test of time-reversal invariance, presumably in the electromagnetic interaction.

The fraction of the data now analyzed has been divided into neutron energy bins 100 MeV wide, centered at 350, 450, 550, and 650 MeV. A comparison with the inverse reaction shows good agreement for the 350- and 650-MeV bins, and a systematic disagreement for the remaining two, which reaches a value of three standard deviations for the 550-MeV bin.

A final remeasuring of the γ detector film has been completed, and the remaining data are now being processed through the computer programs.

A report on this experiment was given at the Columbia University Conference on High

Energy Physics and Nuclear Structure, September 1969.[1]

*University of California–Los Angeles.
†University of Michigan, Ann Arbor, Michigan.
1. B. Schrock, R. Haddock, J. Helland, J. Deteouf, M. Longo, S. Wilson, K. Young, D. Chang, V. Perez-Mendez, and J. Sperinde, An Experimental Test of T Invariance in the Photodisintegration of the Deuteron (UCRL-19350, Oct. 1969); in Proceedings of the Third International Conference on High Energy and Nuclear Physics, Columbia University, September 1969 (to be published).

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

Johnie Sperinde, Benjamin M. Smith, Victor Perez-Mendez, and Don Fredrickson

A large part of the data for the reaction $\pi^- + {}^3He \rightarrow 3n$ has been analyzed. Present indications are that there is a significant difference between the 3n distribution obtained and that expected from phase space alone. This agrees with the results of our previous $\pi^- - {}^4He$ experiment. Current efforts are directed to eliminating any possible systematic errors, determining the effect of the background, and completing the analysis of the remaining data.

π^0 FORM FACTOR EXPERIMENT

Albert W. Stetz, Benjamin M. Smith, Victor Perez-Mendez, and Don Fredrickson

An experiment to measure the form factor of the π^0 meson by studying wide-angle Dalitz decays was begun at the 184-inch cyclotron in July 1969. The experiment makes use of magnetostrictive spark chambers to measure the vector momentum of the two electrons in the decay $\pi^0 \rightarrow e^+e^-\gamma$. This experiment was set up in the Meson Cave and is now in progress.

PHOTOPRODUCTION OF VECTOR MESONS (SLAC)

Victor Perez-Mendez, Albert W. Stetz, Stephen H. Williams, F. Bulos,* R. Giese,* R. Larsen,* D. Leith,* B. Richter,* and W. Busza*

The final results for the photoproduction of ρ^0 mesons from solid targets at 9 GeV were published in Phys. Rev. Letters. The data on photoproduction at 5 and 7 GeV from solid targets and at 9 GeV from hydrogen are currently being prepared for publication. In these reports we show that the ρ-N total cross section is 30 ± 5 millibarns at 9 GeV, and from the application of the vector dominance model, we obtain a value for the ρ-photon coupling constant of $\gamma_\rho^2/4\pi$ 1.1 ± 0.2. The data taken with the bremsstrahlung beam at energies from 12 to 16 GeV are still being analyzed.
*Stanford Linear Accelerator Center.

INSTRUMENTATION

R. Grove,* J. Stoker,* A. Rindi,† H. Wollenberg,† and Victor Perez-Mendez

We have continued to test the resolution of an array of two wire chambers for use with positron-emitting isotopes as an imaging device for medical diagnostics.

We also applied one of our chambers to the problem of measuring the spatial distribution of stopping π^- beams in tissue-like material.[1] 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 pion-beam cancer therapy at the high-current accelerators under construction at Los Alamos and other laboratories.

We have done some developmental work on proportional wire chambers and showed that the current pulses and hence the particle positions could be determined by delay-line techniques using ferrite-loaded electromagnetic cables.[2]

The helium-filled streamer chamber system which was used in a previously reported cyclotron experiment was written up and has been published.[3]

* Electronics Group, LRL.
† Health Physics Group, LRL.
1. A. J. Miller, M. R. Raju, A. Rindi, V. Perez-Mendez, and J. Sperinde, A Method for Mapping the Spatial Distribution of Stopping π^- Mesons in Tissue, UCRL-19376, Oct. 1969.

2. A. Rindi, V. Perez-Mendez, and R. L. Wallace, Delay-Line Readout for Proportional Chambers (UCRL-19255, July 1969), Nucl. Instr. Methods (to be published).
3. Albert W. Stetz and V. Perez-Mendez, Development of a Helium-Filled Streamer Chamber System, Nucl. Instr. Methods 73, 34 (Aug. 1969).

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1. R. J. Cence, B. D. Jones, V. Z. Peterson, V. J. Stenger, J. Wilson, D. Cheng, R. D. Eandi, R. W. Kenney, I. Linscott, W. P. Oliver, S. Parker, and C. Rey, Phys. Rev. Letters 22, 1210-14 (1969).

2. 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 (UCRL-19348, September 1969); in Proceedings of the Third International Conference on High Energy Physics and Nuclear Structure, New York, September 1969 (to be published).

3. B. Schrock, R. Haddock, J. Helland, J. Deteouf, M. Longo, S. Wilson, K. Young, D. Cheng, V. Perez-Mendez, and J. Sperinde, An Experimental Test of T Invariance in the Photodisintegration of the Deuteron (UCRL-19350, Oct. 1969); in Proceedings of the Third International Conference on High Energy and Nuclear Physics, Columbia University, September 1969 (to be published).

4. A. J. Miller, M. R. Raju, A. Rindi, V. Perez-Mendez, and J. Sperinde, A Method for Mapping the Spatial Distribution of Stopping π^- Mesons in Tissue, UCRL-19376, Oct. 1969.

5. A. Rindi, V. Perez-Mendez, and R. L. Wallace, Delay-Line Readout for Proportional Chambers (UCRL-19255, July 1969) Nucl. Instr. Methods (to be published).

6. Albert W. Stetz and V. Perez-Mendez, Development of a Helium-Filled Streamer Chamber System, Nucl. Instr. Methods 73, 34 (Aug. 1969).

EXPERIMENTAL PHYSICS

Wilson M. Powell and Robert W. Birge in charge

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

George E. Kalmus and James Louie

Analysis of the production angular distributions and polarizations in the above reaction at seven incident π^+ momenta between 1.34 and 1.85 GeV/c, representing the c.m. energy range 1850–2090 MeV, is almost complete. The data are being analyzed in terms of (a) an s-channel partial-wave analysis, and (b) an alternative method, in which resonant amplitudes are put into the s channel, and t- and u-channel exchanges constitute the "background" amplitudes.

The results from this work will be published shortly. Film of an additional three incident π^+ momenta has been taken at the Bevatron and is being processed.

RESONANCE PRODUCTION IN π^+p INTERACTIONS AT INTERMEDIATE ENERGIES

George Gidal, Donald F. Grether, Winston Ko, Frederick W. Lott, and Robert W. Birge

Since the most recent semiannual report we have taken 300 000 pictures in the 25-inch bubble chamber, divided about equally between 2.3 and 2.5 GeV/c incident π^+ momenta. This film supplements the data at 2.7 GeV/c and between 3 and 4 GeV/c.

The analysis of the reaction $\pi^+p \rightarrow \pi^0\Delta^{++}$, described in the preceding report, has been published.[1] Approximately 50 000 additional two-prong events at 2.7 GeV/c are currently being measured on the FSD. These events will allow a more detailed comparison of the backward region to s-, t-, and u-channel interpretations.

Work is in progress on $\pi^+\pi^0$ scattering in the region of the ρ^+ from the final state $\pi^+\pi^0p^-$. Preliminary results from the 2.7-GeV/c data show that a Chew-Low extrapolation gives results comparable to those of Baton, Laurens, and Reignier.[2]

About 30 000 four-prong events have been measured at 2.7 GeV/c and about 13 000 at 2.3 GeV/c. Analysis is currently under way on the $\pi^+p\,\omega^0$, $\pi^+p\,\eta^0$, and $\pi^+p\,\pi^+\pi^-$ final states.

1. G. Gidal, G. Borreani, D. Grether, F. Lott, R. W. Birge, S. Y. Fung, W. Jackson, and R. Poe, Phys. Rev. Letters 23, 994 (1969).
2. J. P. Baton, G. Laurens, and J. Reignier, Phys. Letters 25B, 419 (1967).

K^-p EXPOSURES

Robert W. Birge, Daniel Kane, Andrew Van Horn, and John Hoven

Three new momenta have been taken with the K^- beam. Scanning and measuring continue on the COBWEB system. At least one scan has been completed at eleven momenta for three general configurations: events with vees, events with kinks, and three-prong (τ) decays. Roughly 20% has been check-scanned thus far. All but two momenta for the last two configurations have been measured. Cleanup and analysis of events are proceeding.

K^-d AND K^-n ELASTIC SCATTERING

Nathan N. Jew and George E. Kalmus

Work on the K^-d and K^-n elastic scattering reactions was completed.[1] It was found

that the extraction of the K^-n amplitudes depended critically on the fixed input from K^-p models. In order to resolve this, we are making a further study by incorporating data from K^-p elastic scattering and charge exchange.

1. Nathan N. Jew, K^--n Elastic Scattering from $K^-d \rightarrow K^-d$ and $K^-d \rightarrow K^-pn$ at 1 GeV/c, UCRL-19359, Oct. 1969.

TWO-PRONG EVENTS IN π^+p FILM BETWEEN 1.3 AND 1.85 GeV/c

Robert W. Birge and George E. Kalmus

This work is in collaboration with a group at the University of California at Riverside.

Analysis of about 200 000 two-prong events is proceeding.

DATA REDUCTION

Robert W. Birge and P. Wes Weber

With an average of 18.0 (full-time equivalent) visual measurement personnel, the following data reduction was accomplished in the past 6 months.

SCANNING

(all results from 25- inch hydrogen bubble chamber)

Experiment	Beam	Number of frames	
		COBWEB System	FSD System
45-47	1.25- to 1.85-GeV/c π^+	511 225	40 969
50-52	1.1- to 1.6-GeV/c K^-	373 639	1 560
53-55	2.3- to 2.7-GeV/c π^+	9 164	444 296
	Subtotal	894 028	486 825
	Total		1 380 853

Measuring

	Measuring hours	Number of events	Events per measuring hour
COBWEB System			
(One measuring microscope, two MP1-type Franckensteins)	2 472	56 643	22.9
FSD System			
(Two SP5B-type image plane digitizers)	2 643	65 889	24.9
	5 115	122 532	

EXPERIMENTAL PHYSICS

Emilio Segrè and Owen Chamberlain in charge

PROTON-DEUTERIUM INTERACTIONS IN THE INTERMEDIATE ENERGY RANGE

Eugene Colton and W. Chinowsky

We are measuring and analyzing p-d film at 6 GeV/c. The topologies of interest include three, four, five, and six 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 t 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 indicating the number of π mesons produced, and p_s stands for 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.

LOW-ENERGY π^-p INTERACTIONS

W. Chinowsky, W. R. Gage, J. H. Mulvey,* and D. H. Saxon*

The experiment with 456-, 500-, and 552-MeV/c interactions in the Saclay bubble chamber has been completed. A paper reporting the results is in preparation. Analysis with isobar model including $\Delta\pi$ and $N\sigma$ intermediate states yields good fits to effective mass and angular distributions. Waves with angular momentum $J \leq 3/2$ and isotopic spin $T = 1/2$ are considered. Of these the $P_{1/2}$ and $D_{3/2}$ have the largest amplitudes. The $P_{1/2}$ wave inelasticity, although somewhat smaller than that inferred from elastic phase-shift analysis, rises with incident pion energy, consistent with the 1470-MeV resonance behavior. Fits were obtained with two different forms for $\pi\pi$ $T = 0$, $S = 0$ interaction. One, obtained by Lovelace using the Veneziano model, yields roughly equal branching ratios for $P_{1/2}$ into $\pi\Delta$ and $N\sigma$. The other, with zero scattering length, yields very small $\pi\Delta$ branching ratio.

First measurements of some 25 000 events, at 580 MeV/c incident momentum, and an independent scan have been completed. Analysis is proceeding to determine kinematic fits to select examples of $\pi^-\pi^+n$ and $\pi^-\pi^0p$.

*Department of Nuclear Physics, Oxford University, Oxford, England.

PROTON-PROTON INTERACTIONS AT 6 GeV/c

S. Klein,* W. Chinowsky, R. R. Kinsey,† M. Mandelkern,‡ J. Schultz,‡ and T. H. Tan**

A paper reporting results on strange-particle production in four-body states has been accepted for publication in The Physical Review. For a summary of results see Stanley L. Klein, Four-Body Strange Particle

Production in pp Collisions at 6 BeV/c (Ph. D. Thesis), UCRL-18306, Sept. 1968.
*Present address: Institut für Hochenergiephysik, Universität Heidelberg, Heidelberg, Germany.
†Present address: Department of Physics, Brookhaven National Laboratory, Upton, Long Island, New York.
‡Present address: Department of Physics, University of California-Irvine.
**Present address: Department of Physics, University of Colorado, Boulder, Colorado.

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, Roger L. Cottrell,† John Litt,† Luke Mo,‡ and Richard Taylor†

To test the theory of Bernstein, Feinberg, and Lee[1] that the CP violation in K decay is due to C_{strong} (particle-antiparticle conjugation) $\neq$ C_{EM} (charge conjugation), we have looked for a T violation in the reaction $ep \rightarrow eN^*$. We used a polarized proton target (butanol at 1° K with 14% by weight free protons), the SLAC 20-GeV spectrometer to detect the scattered electrons in a 10-counter missing-mass hodoscope, and SLAC electrons at 18 and 15 GeV and positrons at 12 GeV.

A dependence of the differential cross section on the polarization of the target would constitute an asymmetry and would indicate a T violation or second-order corrections to the one-photon-exchange approximation.

A total of 100 million counts was obtained at squared momentum transfers q^2 of 0.4, 0.6, and 1.0 $(GeV/c)^2$ with electrons and 0.4 with positrons. By reversing the sign of the target polarization every 3 minutes we were able to practically eliminate the effect of systematic drifts. Our newly developed butanol target, horizontal cryostat, and fast readout were essential in this experiment to enable us to (a) reverse polarization rapidly, (b) achieve high radiation resistance (3×10^{14} minimum-ionizing particles per cm^2 to reduce polarization to 1/e of its initial value), and (c) warm the target rapidly to anneal out some radiation defects and to change target rapidly.

Preliminary analysis indicates our data are consistent with no T violation to a level of a ± 3% change in cross section on pure hydrogen due to a change of 100% to 0% in target polarization (known as the asymmetry parameter) at each of several N^* resonances and at each q^2.

Further analysis is being continued in Berkeley.

*Present address: CERN, Geneva, Switzerland.
†Stanford Linear Accelerator Center, Stanford University, Stanford, California.
‡Present address: Physics Department, University of Chicago, Chicago, Illinois.
1. Bernstein, Feinberg, and Lee, Phys. Rev. 139, B1650 (1965).

SEARCH FOR POLARIZATION IN ELASTIC ep SCATTERING

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

In an effort to find contributions of two-photon exchange to the electromagnetic interactions 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 preliminary results reduced to pure hydrogen (100% polarized).

E_0 (GeV)	q^2 $(GeV/c)^2$	Polarization
15	0.4	0.016 ± 0.027
18	0.6	0.004 ± 0.011
18	1.0	0.014 ± 0.024

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

Charles Morehouse, M. Borghini,* A. Boyarski,† Owen Chamberlain, R. Diebold,‡ S. Ecklund,† Raymond Fuzesy, William Gorn, Y. Murata,‡ Thomas Powell, B. Richter,‡ Peter Robrish, Stephen Rock, R. Siemann,‡ Stephen Shannon, Gilbert Shapiro, and Howard 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 experiment was performed during October at SLAC, using the butanol polarized target setup of the "Search for T Violation in Inelastic e-p Scattering" experiment, E29. As in the inelastic e-p scattering experiment, the protons were polarized perpendicular to the scattering plane, and the sign of polarization was controlled by a 0.3% shift in the frequency of the pumping microwaves. The beam used for the photoproduction was the bremsstrahlung beam previously used by Boyarski et al.[1] 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 $\approx 20\%$. We found that the target depolarized to 1/e of its initial polarization upon irradiation by 1×10^{15} equivalent quanta/cm^2 (this compares to similar effects due to 3×10^{14} minimum-ionizing particles/cm^2).

We ran at five values of momentum transfer, t, for laboratory-system 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 5-GeV data peak at $-t \approx 0.63$ $(GeV/c)^2$ with an asymmetry of about 70%, and the 16-GeV data peak at $-t \approx 0.08$ $(GeV/c)^2$ with an asymmetry of about 80%. The shapes of the 5-GeV and 16-GeV data as a function of t are different. It is interesting to compare the asymmetry in photoproduction (as reported here for E_0 = 5 GeV) with the asymmetry in the neutron-proton charge-exchange reaction at 5 GeV as reported in the following paper. The magnitudes are closely similar but the signs are opposite when referred to the normal direction, defined by the cross product of the initial proton momentum with the final neutron momentum.

We will be analyzing the data over the winter and expect to publish by spring. 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; we hope to recover the asymmetries, if any, from these reactions in our analysis. However, the statistical quality of these measurements is low.

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†Stanford Linear Accelerator Center, Stanford University, Stanford. California.
‡Argonne National Laboratory, Chicago, Illinois.

1. A. Boyarski et al., Phys. Rev. Letters 20, 300 (1968).

POLARIZATION IN BACKWARD np SCATTERING AT 3 TO 6 GeV

Peter Robrish, Owen Chamberlain, Richard D. Field, Jr., Raymond Z. Fuzesy, Michael J. Longo,* Charles Morehouse, Thomas Powell, Stephen Rock, Stephen Shannon, Gilbert Shapiro, and Howard Weisberg

We have finished a preliminary analysis of the data, which we are now preparing for publication. We have found that the variation of polarization with the invariant momentum transfer variable u may be approximated quite well by the empirical function $P(-u) = -0.5\sqrt{-u}/M_{proton}$. Our sign convention for P corresponds to defining the normal to the scattering plane as the vector product of the incident and scattered neutron momenta. The polarization exhibits little energy dependence over our range of momenta. We are now beginning a more thorough phase of analysis, in which we will try to recover events lost due to spark chamber inefficiencies, in order to improve the statistics of our results.

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

Roger H. Hildebrand,* Joseph Klems,* and Rae Stiening

Our counter experiment to search for this decay mode has been in operation at the Bevatron since the latter part of June. Very early in the experiment we reached our original goal of showing that this decay occurs less frequently than once in 10^5 K^+ decays. Additional running, which is now in progress, will permit us to increase by a factor of 10 the sensitivity of our experiment. We have also made a short run with our apparatus slightly modified so that we may search for reactions such as $K^+ \rightarrow \pi^+ + \gamma + \gamma$ and $K^+ \rightarrow \pi^+ + \gamma$. These data have not been analyzed.

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KAONIC ATOM X RAYS

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

Analysis of the kaonic x-ray spectra of some of the medium and heavy elements showed that K^- are captured on the nuclear surface at a higher rate than can be accounted for by the conventional nuclear charge distribution. Presumably this indicates a low density distribution of neutrons above the nuclear surface.

Preparations for the next experiment at the Bevatron are in progress. We plan to measure the spectra of as many elements as possible from lithium through uranium. Using pure isotopes as targets, we will investigate the effect on the intensity of certain strongly absorbed lines due to the number of neutrons. Considerable effort will be used in the study of the isotopes of samarium, where nuclear deformation should influence the kaon capture rate.

We will look for more x-ray lines that indicate the formation of Σ^--hyperonic atoms.

*Present address: Department of Physics, University of Wyoming, Laramie, Wyoming.

PUBLICATIONS AND PAPERS

1. Peter Klaus Kijewski, π^0 Energy Spectrum in $K^+ \rightarrow \pi^0 \mu^+ \nu$. Search for Direct Radiation in $K^+ \rightarrow \pi^+ \pi^0 \gamma$ (Ph. D. Thesis), UCRL-18433, June 1969.

2. Georges-André Grin and Raymond Kunselman, Solid-State Effects on Pionic Atom x-Ray Spectra (UCRL-18499, May 1969), submitted to Phys. Letters B.

3. D. Cutts, R. Stiening, C. Wiegand, and M. Deutsch, Measurement of the Muon Polarization Vector in $K^+ \rightarrow \pi^0 + \mu^0 + \nu$, Phys. Rev. 184, 1380 (1969).

4. Clyde Wiegand, Measurement of K^--Mesonic x-Ray Spectra of Medium and Heavy Elements, Phys. Rev. Letters 22, 1235 (1969).

5. Clyde E. Wiegand and Raymond Kunselman, Measurements of Kaonic x Rays of Medium and Heavy Elements (UCRL-18891, April 1969), submitted to International Conference on Hypernuclear Physics, Argonne National Laboratory, May 5-7, 1969.

6. Raymond Kunselman and Clyde E. Wiegand, Kaon Mass Measurement from Kaonic Atom x Rays (UCRL-19251, July 1969), submitted to International Conference on Hypernuclear Physics, Argonne National Laboratory, May 5-7, 1969.

7. Clyde E. Wiegand, Measurement of Kaonic x-Ray Spectra and the Capture of Kaons on Nuclear Surfaces (UCRL-18891 Revised), submitted to The Third International Conference on High Energy Physics and Nuclear Structure, Columbia University, September 8-12, 1969.

8. S. Klein, W. Chinowsky, R. R. Kinsey, M. Mandelkern, J. Schultz, and T. H. Tan, Four-Body Strange-Particle Production in pp Collisions at 6 GeV/c (UCRL-19305, Oct. 1969), submitted to Phys. Rev.

ATOMIC BEAM GROUP

Howard A. Shugart in charge

STUDIES IN LOW ENERGY NUCLEAR PHYSICS AND IN ATOMIC PHYSICS

Members of the atomic beam group share the common interest of seeking mechanical and electromagnetic properties of atoms, molecules, and nuclei, and of testing some of the fundamental concepts of physics. These goals are pursued by using principally the techniques of atomic and molecular beams and of optical and electron pumping. The work is carried out on both stable and radioactive materials. Owing to the relative simplicity of the isolated atoms under study, interpretation of results takes on a particularly unambiguous form. This, coupled with the sensitivity of the methods employed, makes possible high-precision measurements and the detection of small departures from accepted laws. In addition, the group explores new techniques that hold promise of extending our investigations and revealing a better understanding of physical laws.

A summary of on-going projects is contained in the following list:

Time-Reversal Invariance in the β Decay of ^{19}Ne (Girvin, Calaprice, and Commins)

Effect of Weak Interaction on the Strong Interaction (Simmons and Commins)

Isotope Shifts and Atomic Stark Effect in Stable and Radioactive Atoms (Yellin and Marrus)

Lifetime of Metastable Electronic States (Van Dyck, Johnson, and Shugart)

Lamb Shift by Quantum Beats and Related Phenomena (Hadeishi)

Coherence Effects in He (Geneux)

Development of an Optical Pumping Mercury Magnetometer (Hadeishi)

Fine Structure of Helium-Hyperfine Structure in ^{3}He (Johnson)

The Hanle Effect and Resonances in the Hydrogen Molecule (Prior and Johnson)

Search for a Possible Electron Mass Shift (Mowat, Johnson, and Shugart)

Spins and Moments of Radioactive Germanium Isotopes (Oluwole and Schmelling)

Spins and Moments of Radioactive Thulium Isotopes (Schmelling)

Spectrum of a Free Radical of Interest to Radioastronomers (Zak, Schmelling, and Shugart)

Universal Mass Spectrometer Detector for Atomic Beams (Zak)

Computations in Nuclear Structure (Ross-Bonney)

Lifetime of the Two-Photon Decay of Highly Ionized One-Electron Atoms (Schmieder and Marrus)

Studies of the $^{2}S_{1/2}$ Ground State of the Mercury Ion (Wang and Hadeishi)

Polarization Correlation of Successive Photons in Atomic Decays (Friedman and Commins)

The activity of the group during the past six months can be indicated by the following enumerations of papers published and reports issued.

PUBLICATIONS AND PAPERS

Abstracts

1. Murray Steinberg and Howard A. Shugart, On the Radiative Lifetime of the 2 $^1S_0$ Metastable State in Helium, Bull. Am. Phys. Soc. 14, 32 (1969).

2. Joseph Yellin, Richard Marrus, and Edmond C. Wang, Atomic Beam Study of the ^{39}K, ^{42}K Isotope Shift, Bull. Am. Phys. Soc. 14, 85 (1969).

3. J. Richard Mowat, Charles E. Johnson, Vernon J. Ehlers, and Howard A. Shugart, Search for an Electron Mass Shift in ^{133}Cs, Bull. Am. Phys. Soc. 14, 524 (1969).

4. Charles E. Johnson, Michael H. Prior, and Howard A. Shugart, Hyperfine Structure of g_J of ^{129}Xe in the $5d[3-1/2]_4$ State, Bull. Am. Phys. Soc. 14, 52 (1969).

5. A. A. Ross-Bonney, Shell-Model Calculation for Non-Closed Shells, Bull. Am. Phys. Soc. 14, 626 (1969).

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7. Charles E. Johnson, 3^3P Hyperfine Structure of ^3He, Bull. Am. Phys. Soc. 14, 953 (1969).

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Theses

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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 continued 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-inch 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 nine references is included in the preceding Semiannual Report, UCRL-18877, page 61), we have, in the past 6 months, published work on two additional projects and have work either in press or in the final stages of writing on three new projects.

1. The work reported last time on the five- and six-body final states $K^+p\pi^+\pi^+\pi^-$ and $K^0p\pi^+\pi^+\pi^-\pi^0$ has been published in the Physical Review.[1] In it we observe (a) strong A_1 meson production, (b) the K(720) enhancement, which we demonstrate to be a reflection of the Δ^{++}_{1236}, and (c) a possible new K^* resonance at mass 2640.

2. Our complete analysis of the Q enhancement in the four-body final states $K^+p\pi^+\pi^-$ and $K^0p\pi^+\pi^0$ has been published in Nuclear Physics B.[2] We confirm our previous result on the splitting of the Q and demonstrate that a consistent description of the decay characteristics requires either an interference effect between the $K^*_{890}\pi$ and $K\rho$ decay modes or a $K\epsilon^0_{720}$ decay mode, or both.

3. We have studied the reaction $K^+p \to K^0\pi^+p$ 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% pseudoscalar 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 that the cross sections for $K^+p \to K^*_{890}p$, $K^*_{1420}p$, and $K^0\Delta^{++}_{1236}$ appear to fall more rapidly with incident momentum than the predictions by a simple Regge-pole exchange model. This work is to be published in Nuclear Physics.[3]

4. We have analyzed reactions of the type $K^+p \to \bar{Y}NN(\pi)$, where $\bar{Y}$ refers to a $\bar{\Lambda}$ or $\bar{\Sigma}$ antihyperon, $K^+p \to \bar{\Xi}^-YN(\pi)$, and $K^+p \to K^+p\bar{p}p$. With twice the data previously reported we observe again an enhancement in the $\bar{\Lambda}N$ system at M = 2240 MeV, and also observe this enhancement in the nonexotic $\bar{\Sigma}^{\pm}N$ final states. Cross sections and production characteristics of all the final states involved are presented. This work is also to be published in Nuclear Physics.[4]

5. We have performed an exhaustive study of the final state $K^+\pi^-\Delta^{++}$ in reaction $K^+p \to K^+\pi^-\pi^+p$, 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, the $K\pi$ and Δ^{++} decay angular distributions, the spin-density matrix elements, the $K\pi$ asymmetry, and the $K\pi$ mass spectrum. The implications of these results on s-wave K^* resonances are presented. This work has been submitted to Nuclear Physics B.[5]

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K^+D INTERACTIONS AT 12 GeV/c

Alexander Firestone, Gerson Goldhaber, and David Lissauer

We have begun scanning and measuring the 525 000 stereo exposures of K^+D interactions at 12 GeV/c taken in April 1969 at the SLAC 82-inch 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 (a) a visible K^0 decay, or (b) any three-pronged event, or (c) 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-ω candidates, which are characterized by a vee coming from a charged decay. Preliminary cross-section estimates have been obtained for the final states K^0pp, $K^0pp\pi^0$, $K^0pn\pi^+$, $K^+\pi^-pp$, $K^+\pi^+\pi^-d$, and $K^0\pi^+\pi^-pp$. 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 more than 1500 events in the final state $K^+\pi^+\pi^-d$. In addition, the cross sections for the charge-exchange reactions $K^+n \rightarrow K^0p$, $K^+n \rightarrow K^{*0}p$, and $K^+n \rightarrow K^0\Delta^{++}$ at this high momentum will be important for Regge theories of high energy phenomena.

π^+p INTERACTIONS AT 3.7 GeV/c

Donald G. Coyne, W. Ralph Butler, Bronwyn H. Hall, Jimmy N. MacNaughton, Gerson Goldhaber, and George H. Trilling

We are continuing analysis of the data from the 180 000-picture sample of $\pi^+p \rightarrow$ all event types. The experiment was done in the LRL 72-inch 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) are being processed by a new program designed to closely simulate the action of the physicist, using the FSD (Flying Spot Digitizer) ionization information. This program has been tested against the first third of the data.

New information since our most recent 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 are being 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 $\pi^+p \rightarrow \pi^+\pi^0p$ 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 both in our data and in independent reactions. The destructive interference observed has been interpreted by a theory of A. 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

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

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

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

IONIZATION MEASUREMENT BY THE FSD

Kwing L. Chan, Jimmy MacNaughton, W. Ralph Butler, and Donald G. Coyne

A study concerning the relation between the number of "hits" and "misses" recorded by the FSD while measuring a track and the mass and momentum of the particle was conducted. A number of empirical corrections were made which led to separation of protons from π mesons with an accuracy of 98% for momenta less than 1400 GeV/c.

K^+p ELASTIC SCATTERING AT 4.6 GeV/c

George H. Trilling, Frane Marcelja, and Jimmy MacNaughton

A Nuclear Physics B paper on this subject was finished and submitted. The cross section and angular distributions were presented for our data and compared with data at other momenta. It was shown that all the data on the forward diffraction peak for momenta between 1.2 and 14.8 GeV/c could be fitted reasonably well by $\frac{d\sigma}{dt} = \left(\frac{d\sigma}{dt}\right)_0 e^{Bt}$, $B = 6.8\,\beta^2$, where β is the center-of-mass velocity of the K^+p system.

Λp AND Λd INTERACTIONS

John A. Kadyk, George H. Trilling, Gideon Alexander, P. J. Gaposchkin, and John M. Hauptman

Analysis is now in progress on almost the entire sample of 267 000 pictures taken in the 25-inch hydrogen chamber to study Λp interactions. The platinum plate installed inside was used as a target for 1.5-GeV/c K^- to generate the Λ beam. All the film has been scanned, and almost all events have been measured. Nearly 200 elastic Λp interactions should be present in the final sample, several times the previously published data in this energy range, 300 to 1500 MeV/c. In addition, about 30 reactions of the type $\Lambda p \to \Sigma^0 p$ should be present. The dynamics of these reactions are being studied via the Λp total and differential cross sections as a function of Λ momentum; in addition, the Λ decay yields polarization information.

A preliminary analysis based on one-half the total data appears to indicate the Λp elastic cross section increases somewhat at about 640 MeV/c, but does not reach the $^3S_1$ unitarity limit required by a Λp resonance suspected near this momentum. A second prominent peak seems to occur at about 1300 MeV/c Λ

momentum. Although the angular distributions are consistent with isotropy, there is an indication that some forward peaking occurs for the Λ interactions at the higher momenta.

A recent run in the 25-inch chamber filled with deuterium yielded 94 000 pictures, in which the internal plate was used as a target for 1.9-GeV/c K^-. Studies will be made primarily of the inelastic reactions $\Lambda n \rightarrow \Sigma^- p$ and $\Lambda n \rightarrow \Lambda \pi^- p$. These new data are in the early stages of analysis and no results are yet available.

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

John A. Kadyk, Jonathan Chan, George H. Trilling, and Gerson Goldhaber

Analysis of the low-energy K^0_{2p} and K^-p interactions is continuing toward the goal of a partial-wave analysis of the final data. A substantial number of remeasures are still to be done for the K^-p interactions, but the K^0_{2p} data are now complete. We expect to extract the best possible parameters describing the $I = 1$ channel $\bar{K}N$ interactions, and perhaps also equivalent information concerning KN interactions at low energies. Several independent analyses have already been made by outside groups, relying strongly on incomplete samples of our data.

After obtaining the $\Lambda\pi^0$ cross section from the K^-p data, we expect to use this to determine the K^0_{e3} absolute decay rate in the K^0_2 film, normalizing the $\Lambda\pi^+$ reactions in the same pictures. This portion of the analysis is virtually complete.

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PLASMA PHYSICS

C. M. Van Atta in charge

RESEARCH PROGRAMS

The Plasma Physics Group continued to conduct experimental and theoretical research on basic plasma and related atomic physics problems. A study of the effect of high-frequency electric fields on the profiles of emission lines is yielding excellent results that permit quantitative comparison with theory. These observations are now being used to analyze the high-frequency oscillations in a beam-plasma system. The exploration of a high-current sheet pinch plasma by means of laser-beam photon scattering is making very good progress. Formation of a "snow plow" and pinch compression, as well as subsequent instabilities, are readily discernible. The steady-state microwave-generated plasma source has been performing reliably. The program with this facility includes feedback stabilization, wave propagation experiments, and a study of the effect of finite gyroradii on the response of Langmuir probes of various sizes. The equipment for injection and trapping experiments with laser-produced plasma is in construction.

An experiment to identify and suppress some of the low-frequency modes that affect plasma transport across magnetic fields has been started in a hollow-cathode discharge apparatus. Mode identification is still incomplete, but suppression of an instability, and consequent reduction of cross-field transport, has been achieved under some conditions.

Two continuing atomic physics experiments connected with the production of high-temperature plasmas are yielding results. One is the production of highly excited neutral beams by charge exchange at the surfaces of materials deposited under ultrahigh-vacuum conditions. The second concerns the production and destruction of metastable hydrogen molecules in metal vapors.

Theoretical efforts in the field of plasma physics include a continuing study of end effects in open-ended magnetic confinement systems, and an investigation of the Darwin model of electrodynamics as a possible simplification for computer simulation of plasma behavior. A kinetic theory for the interaction of confined particles and waves in a finite one-dimensional plasma has been completed. The latter is currently being extended to the three-dimensional problem of a plasma slab with a sheared magnetic field in an attempt to obtain kinetic equations for both particles and waves.

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6. Oscar A. Anderson and Wulf B. Kunkel, Tubular Pinch and Tearing Instability, presented at the 1969 APS Summer Meeting, Honolulu.

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25-INCH HYDROGEN BUBBLE CHAMBER

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

The 25-inch hydrogen bubble chamber has continued operation through this report period with no major difficulties. This has resulted in a total production of 1 386 885 pictures for five different experiments.

GAS PURITY

The new Serfass gas purification system has been installed and used for both hydrogen and deuterium, for filling the chamber as well as for pump and purge operations. This filtering unit is made to process both hydrogen and deuterium gas, resulting in residual impurities of less than 10 parts per billion. We do not have available at present the instruments to verify this low level of impurity, but the system seems to be performing satisfactorily. No further difficulties have been encountered during this period with impurities in the helium gas used to operate the chamber fill and vent valves located in the liquid hydrogen. We have continued to analyze D_2O for tritium content for this and other laboratories as necessary.

CAMERA OPERATION

The camera has been operating fairly satisfactorily, but requires a rather high degree of maintenance and repair. The conductive rubber on the film drive capstans continues to work well in the elimination of static discharges, and the same material was used on the film clamp rollers that had been making static marks on the edge of the film where position-marking lights are used.

An arrangement of dowels was installed on the camera that enter linear bushings as the camera is placed in position. This system essentially fixes the camera position with respect to the chamber.

As time permits, the following improvements to the camera system will be made: (a) improvement in the individual view alignment; (b) adjustment or redesign to make the advance of the film and the tension on it more uniform; and (c) increase in the reliability of the vacuum valve system.

CHAMBER OPERATING CONDITIONS

Of increasing concern to the physicist have been the bubble density and bubble size. To speed up the evaluation of chamber operation a separate camera was set up, using the view port. This camera takes on Polaroid film an enlarged picture of the center of the chamber, which can then be projected to obtain the desired bubble data. Operating conditions can then be changed immediately to suit the experimenter without the normal delay in film processing. This system has worked well and merits the improvements in the optics that are now in process, to obtain even better resolution.

INTERNAL TARGETS

A test model of a target to be used inside the bubble chamber has been built and will be installed during the next shutdown. The target, of yttrium sulfate, is to be used in a 50 000-picture run, which should afford the

information necessary to determine the feasibility of a proposed polarized target facility to be installed inside the chamber. The target will be mounted on the holder presently used for the platinum target, thus allowing it to be removed from the beam when not in use.

FILM PRODUCTION

Following is a breakdown by experiment number of film production for this period.

Experiment number	Particles	Rolls	Pictures
72	π^+p	124	204 864
73	K^-p	146	239 859
87	π^+p	107	176 864
112	K^+D_2	407	671 091
122	K^-D_2 (platinum target in)	58	94 207
	Total	842	1 386 885

HEALTH PHYSICS

H. Wade Patterson in charge

ENVIRONMENTAL RADIATION STUDY AND DATA PLOTTING

Lloyd D. Stephens

A part of the total environmental radiation monitoring is carried out by the Health Physics Department. We have recently improved our ability to determine the extent of the contribution to environmental radiation caused by the four LRL accelerators. This has been accomplished by adaptation of an existing computer program to accept our telemetered data, which come from a total of ten locations within the Laboratory to a receiving station.

Previously the individual contribution from one accelerator at one location was difficult to determine, but now it can be evaluated with relative ease and with reasonable accuracy.

STUDIES OF RADIOACTIVITY PRODUCED IN ACCELERATOR SHIELDING

Klaus K. J. Goebel

Data analysis for an earlier experiment at the Bevatron was completed, and the results obtained provide information about the contribution by the main constituents of the concrete to the dose at the shielding surface. Also, reduction of the dose rate from thermal neutron absorption in sodium by admixture of boron, and the most effective use of a neutron poison with respect to its spatial distribution inside and on the surface of the shielding, were determined.

DEVELOPMENTS IN GAMMA AND NEUTRON SPECTROSCOPY AND APPLICATIONS TO ACCELERATOR SHIELDING PROBLEMS

Jorma T. Routti

The methods[1] developed for automatic computer analysis of γ-ray spectra from Ge(Li) detectors have been applied to study of spallation reactions induced by high-energy particles in medium-heavy targets. We have made preliminary studies using such reactions as threshold detectors to study the characteristics of high-energy particle fields inside accelerator shields.

For the determination of high-energy neutron spectra from the measured responses of these and other threshold detectors, two new numerical methods have been developed for the solution of first-order Fredholm integral equations.[2,3] These methods have been applied also to other problems of similar mathematical nature.[4]

Knowledge of neutron spectra inside the shields can be used to verify simplified methods of calculating the dose rates and required shielding thicknesses.[5]

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BEAM MONITORING AND SHIELDING STUDIES FOR THE ELECTRON RING ACCELERATOR

Lloyd D. Stephens, Klaus K. J. Goebel, and Joseph B. McCaslin

We studied the possibilities for monitoring protons and heavy ions accelerated in the electron ring accelerator (ERA). A number of proton reactions and detection possibilities were proposed, and some cross-section and threshold calculations were made for heavy-ion reactions of the type $^{138,140}Ce(N, 5n)^{149}Tb$. Experimental verification with a nitrogen beam of 55.4 MeV from the 88-inch cyclotron showed that the production rate for ^{149}Tb is within a factor of two in agreement with the estimations made.

A beam stopper for the 4-MeV 1000-A electron beam of the Astron injector was designed. Its performance has been checked and found satisfactory for safe working conditions near the ERA compressor.

BEVATRON TOTAL BEAM MONITORING

Joseph B. McCaslin

In conjunction with further development of the high-energy threshold detector system, $Hg \rightarrow {}^{149}Tb$, the Health Physics group has assisted experimenters at the Bevatron and 184-inch cyclotron in making measurements of beam distribution and absolute beam intensity using the $Au \rightarrow {}^{149}Tb$ reaction. Application of this technique has been found especially useful during some phases of development work on the Bevatron resonance extraction system.

DEVELOPMENT OF TECHNIQUES FOR APPLYING ACTIVATION ANALYSIS TO PROBLEMS OF BEAM MONITORING AND INDUSTRIAL HYGIENE

Alan R. Smith

We continue to extend applications of high-resolution Ge(Li) semiconductor detector γ-ray spectroscopy. The resultant complex γ-ray spectra, typically containing 30 to 60 significant peaks, can be analyzed rapidly and automatically with our computer program SAMPO, thus permitting us to process data from many samples with a minimum of human effort. This system has been put to use at both the 184-inch cyclotron and the Bevatron for purposes of beam monitoring and particle energy spectroscopy; polyethylene, aluminum, and copper have been used as target materials for production of diagnostic γ emitters.

Other applications, in the category of reactor-based neutron activation analysis, include a pilot study (with Dr. T. Budinger, LRL Berkeley Medical Department) to identify trace elements in blood, and a feasibility study (with L. Hughes, Berkeley Campus Radiological Safety Department) to identify air pollutants. To assist in the often-difficult task of isotope identification, we have completed the initial version of the GOLUX library, which contains decay information for about 1800 radionuclides--including energies and intensities (where known) for more than 11000 γ rays associated with these isotopes. Development of the accompanying automatic computer program for isotope identification is now in progress.

DEVELOPMENT OF SPARK CHAMBERS FOR NEUTRON SPECTROSCOPY AND MEDICAL SCANNING

Alessandro Rindi

1. MEDICAL APPLICATION OF SPARK CHAMBERS

a. Positron source imaging. Work is in progress for improving the resolution of the method.[1]

b. Mapping of π^- stopping region. Experiments have been performed that show the feasibility of using spark chambers for mapping the region where π^- are stopped through the detection of γ rays emitted in the capture process.[2,3] Other experiments are in progress at this time.

2. NEUTRON SPECTROMETER FOR ENERGIES BETWEEN 30 AND 200 MeV

A study of this project is currently in progress.

3. IMPROVEMENT OF MULTIWIRE DETECTING DEVICE

Work is in progress for:

a. Multiwire proportional chamber and consequent readout method.

b. Proportionally triggered spark chambers.

c. Self-sparking multiwire chambers.

1. Harold A. Wollenberg, Alessandro Rindi, Victor Perez-Mendez, and Johnie Sperinde, Summary of Medical Spark Chamber Work, 1968-69, LRL Internal Report, Aug. 1968.
2. A. J. Miller, M. R. Raju, A. Rindi, V. Perez-Mendez, and J. Sperinde, A Method for Mapping the Spatial Distribution of Stopping π^- Mesons in Tissue (UCRL-19376, Oct. 1969), presented at the Boulder Meeting of the Los Alamos Users' Group, October 30-November 1, 1969.
3. Alessandro Rindi, Present and Projected Uses of Multiwire Spark Chambers in Health Physics (UCRL-19363, Oct. 1969), submitted to 2nd International Conference on Accelerator Dosimetry and Experience, Stanford, California, November 5-7, 1969.

RAPID ESTIMATES OF HUMAN EXPOSURE FROM ^{11}C MEASUREMENTS

A. Jerry Miller

A usable method of roughly estimating the radiation dose to individuals in accelerator accidents has been developed. In such accidents, in which individuals are exposed to high-energy charged particle beams of protons or π^+ mesons (or both), the radiation dose can be rapidly estimated by counting the induced ^{11}C activity in the irradiated area with a 3X3-inch portable NaI detector. To obtain the desired lower level of sensitivity (7 to 14 counts/sec-rem above background at 30 min after the exposure) the ^{11}C activity is measured in the Health Physics Department Low-Background Counting Facility. Experiments performed at the Bevatron and the 88-inch cyclotron indicate that the dose estimates made in this manner are accurate to within a factor of 2 times the actual dose.

LASER SAFETY PROGRAM

Joseph B. McCaslin and Lloyd D. Stephens

The laser safety program is conducted by the Health Physics Department. There are approximately 35 lasers in use in nearly as many buildings. Some lasers are located at least semi-permanently in scientific apparatus, while others are portable and used for alignment of devices and beam lines.

Power densities range from 0.7 to 10^9 W/cm^2.

Working with the Medical Services Department, we have agreed upon levels of action, i.e., sign posting, sign posting and instruction, or laser safety class, and--for lasers with a power density greater than 3 mW--an ophthalmological evaluation.

The LRL Livermore Hazards Control Laser Safety Course will be taught in Berkeley for laser users early in 1970.

WHAT QUALITY FACTOR?

H. Wade Patterson

Recently the USAEC published in a chapter of a Manual a table giving quality

factors for neutrons and protons over the energy range from thermal to 2 GeV. The values published are for monoenergetic neutrons and protons, but no official guidance is given for neutron spectra. We have therefore found it useful to calculate average quality factors for a number of typical spectra found in practical situations. One result of the calculation is the finding that proper assignment of a quality factor to a measurement made in rads with a tissue-equivalent ionization chamber, when the maximum neutron energy lies between 1 and 10 MeV, requires a high degree of knowledge about the shape of the spectra, because very small changes in the slope of the neutron spectra can be accompanied by threefold changes in the quality factor.

PUBLICATIONS AND PAPERS

Henry S. Dakin and Lloyd D. Stephens, Environmental Radiation Telemetry System (UCRL-16482 Rev., Sept. 1969), submitted as a note to Health Physics J.

Chun Bin Lim, The Thermal Neutron Flux Produced in a Spherical and a Cubical Cavity by Slowing Down of Fast Neutrons in the Cavity Walls, for Walls of Water and Concrete, as a Function of Cavity Size, Using the Discrete S_n Method (M. S. Thesis), UCRL-19345, Aug. 1969.

J. B. McCaslin and A. R. Smith, Radiation Measurements and Shielding Study of the Berkeley 27-Inch ^{3}He Cyclotron (UCRL-19374, Oct. 1969), submitted to the 2nd International Conference on Accelerator Dosimetry and Experience, Stanford, California, November 5-7, 1969.

H. Wade Patterson, Harry H. Heckman, and Jorma T. Routti, New Measurements of Star Production in Nuclear Emulsions and Applications to High Energy Neutron Spectroscopy (UCRL-19389, Oct. 1969), submitted to the 2nd International Conference on Accelerator Dosimetry and Experience, Stanford, California, November 5-7, 1969.

Alessandro Rindi, Present and Projected Uses of Multiwire Spark Chambers in Health Physics (UCRL-19363, Oct. 1969), submitted to the 2nd International Conference on Accelerator Dosimetry and Experience, Stanford, California, November 5-7, 1969.

Jorma T. Routti, High-Energy Neutron Spectroscopy with Activation Detectors, Incorporating New Methods for the Analysis of Ge(Li) Gamma-Ray Spectra and the Solution of Fredholm Integral Equations (Ph. D. Thesis), UCRL-19514, April 1969.

Jorma T. Routti, Mathematical Considerations of Determining Neutron Spectra from Activation Measurements (UCRL-19375, Oct. 1969), submitted to the 2nd International Conference on Accelerator Dosimetry and Experience, Stanford, California, November 5-7, 1969.

Jorma T. Routti and Ralph H. Thomas, Moyer Integrals for Estimating Shielding of High-Energy Accelerators (UCRL-18862, Apr. 1969), submitted to Nuclear Instruments and Methods.

H. A. Wollenberg and A. R. Smith, Energy and Flux Determinations of High-Energy Nucleons (UCRL-19364, Oct. 1969), submitted to the 2nd International Conference on Accelerator Dosimetry and Experience, Stanford, California, November 5-7, 1969.

Harold A. Wollenberg and Alan R. Smith, Radiogenic Heat Production in Prebatholithic Rocks of the Central Sierra Nevada (UCRL-18823, Apr. 1969), submitted to J. Geophys. Research.

Computing and Data Handling

MATHEMATICS AND COMPUTING

James A. Baker in charge

The Mathematics and Computing Services organization of the Laboratory is administratively a part of the Physics Division, for two reasons: (1) It developed originally as a service needed by physicists, and (2) the major part of its work is still performed for Physics Division programs. Use of these services by other research divisions and by certain administrative and support groups of the Laboratory has increased over the years and now represents approximately 45% of all applications programming and 20% of computer use by activities other than LRL physics-research programs. Reports of applications programming for all users, of systems programming and computer operations which benefit the whole Laboratory, and of the separately budgeted activity in Mathematics and Computer Science Research are included here. This appears to be an effective way to display in one place, for semiannual review, all the work of this organization.

During this period of this report (May 1969 through October 1969), members of the Mathematics and Computing Group provided programming and mathematical consulting services for Laboratory research groups and performed research in mathematics and computer science. The effort may be divided into the following 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 summarizes the work of this Group in the above areas:

I. APPLICATIONS PROGRAMMING

A. PHYSICS

For Powell-Birge Group

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

COBWEB System

The COBWEB I/O Package[1] and trap supervisor, CIO,[2] has been incorporated in the system. A disk section has been added to CIO and a disk package, DSCPG, has been written to handle FORTRAN disk requests. Debugging of disk I/O has not begun.

Several on-line diagnostic routines have been incorporated in COBWEB to aid electronic maintenance personnel. These diagnostic routines operate in real time with the measuring and scanning procedures so that the system need not be taken down to diagnose problems.

Other significant changes in the COBWEB System have been made:

(a) Routines have been provided to allow multilevel reentrance.

(b) Control points previously dedicated to a particular function (that is, scanning or measuring) may now be reassigned alternative

functions.

(c) Through event-type definitions, the sign of curvature for tracks may be checked as part of normal track fitting.

A 6600 program, TRFIT, has been written to study possible refinements to be made in the track-fitting algorithms of COBWEB.

An effort is under way to adapt the track-matching program MATCH[3] used in the COBWEB system. The new program is called SAVE. The matching problem in COBWEB is the occasional reordering of the measured tracks. SAVE will reorder the tracks and eliminate the necessity for remeasuring them. The possibility also exists of changing the COBWEB system so as to measure more than one beam track if it is unclear which track belongs to the event. SAVE would identify the proper beam track.

The main problem in adapting MATCH to SAVE is reducing the size and generality of MATCH to meet the needs of COBWEB. A further problem is the processing of data measured in different units and coordinate systems.

Miscellaneous

A personnel efficiency and attendance evaluation program, SCORE, has been written and is currently in production. The program is running on a weekly basis with input from three sources: a weekly work schedule, a COBWEB scanning-and-measuring log tape for the period, and an FSD road-making tape for the same period. From these data, the following tables are constructed:

(a) Weekly attendance profiles for each person.

(b) Total hours actually worked.

(c) Scanning and measuring rates for each experiment and event type.

(d) Total events measured and total scanned by experiment.

(e) Summaries of all scanning and measuring by machine.

(f) Machine utilization.

(g) Accounting of time spent on tasks other than scanning and measuring.

For the purposes of monthly or semiannual reports, SCORE produces a summary tape to be read by the program SUMMARY, which accumulates the weekly statistics provided by SCORE.

A new program, PREP, has been written and is near completion. PREP provides an up-to-date log of all action taken with regard to a roll of film from original editing through final analysis. This log consists of one record for every combination of roll number, experiment number, and five grouping programs, ITEMS: namely, EDIT (film editing), SCAN (film scanning), MEAS (COBWEB measurement), ROAD (FSD roads), and COBR (COBWEB remeasurement). Each record also contains the nominal momentum of the events on the roll.

From EDIT records, one may obtain the edit date and the total number of good frames for a given roll number. SCAN records provide the starting and ending dates of the first, second, and check scans. MEAS and ROAD records include the starting and ending dates of measurement and road making, respectively. COBR records include the starting and ending dates of FSD remeasurements done on COBWEB.

PREP provides a means of easily updating these records. A summary printout of current status for specified cutoffs on roll numbers, experiment, or momentum is available.

1. Herbert C. Albrecht, Eugene P. Binnal, 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-18877, May 1969, p. 74.
3. S. Penny, MATCH, Group A Programming Report Number P-88, June 3, 1964.

For Trilling-Goldhaber Group

Richard Ahlstrand, Derik Armstrong, Emmett Burns, Bronwyn Hall, James Miller, and John Telford

CHAOS[1] and the Trilling-Goldhaber versions of the programs SIOUX[2] and ARROW[3] were modified and converted to run under the SCOPE compilers. The programs now run with reduced field lengths and decreased running times. SIOUX now runs 20-25% faster.

The programs ARROW, KIOWA,[4] CHAOS, and MLIST[5] are being modified to utilize the Mass Storage System (MSS). The Mass Storage System and the modified programs will allow the user to have his entire experimental data on-line, thereby having the ability to retrieve any subset of his data with a minimum of intermediate steps.

The program NFASE[6] was used on final K^+p elastic scattering data, and the results were published for the Lund International Conference on Elementary Particles.[7] Work is continuing in this area with the program NFASE and the multi-energy program TFASE.

The programs MINMA and FITMA, which incorporate MINFUN[8] and VARMIT[9] respectively, were used to fit the data for the $\omega\rho^0$ interference effect.[10-13]

1. Derik V. Armstrong, CHAOS, Trilling-Goldhaber Physics Note 141, Oct. 10, 1966, and CHAOS NL 1, Jan. 9, 1968.
2. F. J. Solmitz, A. D. Johnson, and T. B. Day, TVGP, Alvarez Group Programming Note P-117, April 1965; and O. I. Dahl, T. B. Day, F. J. Solmitz, and N. L. Gould, SQUAW, Group A Programming Note P-126.
3. Nancy L. Gould, 6600 ARROW SYSTEM, Group A Programming Note P-186, May 1969.
4. Jerry Friedman, Al Rittenberg, and Orin Dahl, KIOWA, Alvarez Programming Group Notes P-171 and P-172, May 1968.
5. Derik V. Armstrong, MLIST, Trilling-Goldhaber Physics Note 151, Oct. 10, 1966.
6. PDSR, UCRL-18877, May 1969, p. 75.
7. B. H. Hall, R. W. Bland, G. Goldhaber, and G. H. Trilling, Partial-Wave Analysis of K^+p Elastic Scattering, UCRL-19231, July 1969.
8. W. E. Humphrey, MINFUN--A General Minimizing Routine, Group A Programming Note P-6, Sept. 7, 1962.
9. Laboratory Computer Center writeups ZO EO ZO13 and ZO EO ZO14 are available in the Computer Center Library (Building 50B, Room 1237A, Extension 5529).
10. G. Goldhaber, W. R. Butler, D. G. Coyne, B. H. Hall, J. N. MacNaughton, and G. H. Trilling, The $\omega\rho^0$ Interference Effect, UCRL-18894, June 1969.
11. W. R. Butler, D. G. Coyne, G. Goldhaber, B. H. Hall, J. N. MacNaughton, and G. H. Trilling, The ϕ/ω and η/η' Production Ratios in the Reaction $\pi^+p \rightarrow \Delta^{++}$ + Boson at 3.7 GeV/c, UCRL-19225, June 1969.
12. G. Goldhaber, W. R. Butler, D. G. Coyne, B. H. Hall, J. N. MacNaughton, and G. H. Trilling, Further Study of the H(990) Effect, UCRL-19229, June 1969.
13. ———, The $\omega\rho^0$ Interference Effect in the $\pi^+p \rightarrow \pi^+\pi^- \Delta^{++}$ Interaction, UCRL-19352, Sept. 1969.

For Lofgren Group

Joan Tyson

The KE2 reconstruction program, KEREC, was improved for production; the output listings were streamlined. SASS[1] input processing was added to the KEREC program. Work was begun on fitting individual spark data and on computing variances.

The reconstruction section of the spark chamber program, SPRKE2, is completed and running. Variances of the reconstructed data are computed. A new section for pattern recognition for a small cylindrical chamber is being added to SPRKE2. Preliminary work is being done in this area to find the fastest and most accurate method for picking the spark and reflection points out of all the data points.

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

For Moyer-Helmholz Group

Fredric Gey and Ruth Hinkins

π^0 Form Factor Experiment

Data acquisition and polynomial track analysis programming for this experiment are nearly complete; orbit analysis programming has been started.

π-^{3}He Experiment

The program EFKE uses a Monte Carlo technique to find the background to double charge exchange of negative pions on ^{3}He from positrons produced in Dalitz decay of neutral pions created by single charge exchange.

NOCNT is a program to find the efficiency of a scintillation counter with respect to neighboring counters of known efficiency. The distribution of counts in each scintillator is known and assumed continuous; efficiency is determined by selecting and fitting a suitable function.

SPRNX is the latest version of the code that does general processing of spark data tapes. The revisions include a new way of processing spark data to retain all possible wires for a given spark, not just the "best" combination, because a more valid determination of which are "best" can be made later. Wires are now allowed to be a component of more than one spark. This program version is compiled under FORTRAN Extended.

For Theoretical Physics Group

Esther Schroeder

Transverse Instability of a Charged-Particle Beam Penetrating a Plasma

A rather general and flexible program, YNJSOL, has been developed in order to study the transverse behavior of an intense beam of charged particles passing through a plasma. The beam is assumed to translate without internal distortion. The force kernel coupling and longitudinal density modular ion of the beam are left quite general. A variety of initial conditions is permitted. The program solves the initial-value problem by integrating simultaneous linear coupled second-order differential equations. Output format and criteria for termination of the computation are left to the user's choice.

Scattering Cross Section

The program GOLSHAN is being written to calculate the scattering cross section for the excitation of ions through electron impact. The scattering amplitude reduces to a one-dimensional path integral. The square of this integral, in turn, is to be integrated to give the total cross section for the process.

B. NUCLEAR CHEMISTRY

Derik Armstrong, Billie Bearden, Noel Brown, Penelope Fink, Harold Hanerfeld, Gerald Litton, Elizabeth Quigg, and Esther Schroeder

MULTI-D Package (Ref. 1)

A PDP-9 computer with 16 K of memory was utilized to control on-line data acquisition for several multidimensional fission-fragment experiments. The controlling programs were variations of the MULTI-D9 package. Automatic monitoring of stabilization peaks provided a means of recognizing detector failures.

PLAY (Ref. 2)

In a continuing effort to utilize more effectively the PDP-9 Computer for spectral analysis, several modifications were made to PLAY. Some of the more significant improvements involved calibration fitting, peak analysis, and hardware control of display parameters.

PDP-7 Hilac Operating System

Two programs are currently being developed to handle multiparameter data. MULTI-D7 is the on-line data-collection program whose principal objective is to record data on magnetic tape. Additional functions are performed to allow the operator to monitor the progress of the experiment. The second program, MULTI-S,[3] sorts data from MULTI-D7 recorded output. Although working versions of these programs exist, improvements are being made to (a) allow higher data-input rates; (b) perform multiple sorting of data

according to preset parameters; (c) incorporate the programs into the PHA 1969 Operating System.[4]

Four-Dimensional Sorting

The programs 4DSORT sorts four-dimensional data from MASORT,[5] a 6600 program used in the study of the fission process. The results of the sort are discrete γ- and x-ray spectra, defined on mass and kinetic energy and corresponding x-ray and γ-ray energy by "windows." Input to initiate a run is read via teletype. A maximum of 8 hours of sorting can be done without operator intervention, and all resultant spectra are written on DEC tape with appropriate identification. The user may also request a matrix of mass intervals versus x-ray energy.

Charge Distributions

The equilibrium charge distributions of heavy elements at a given velocity are calculated. This has been accomplished by fitting experimental data to specific functions, using programs FIT[6] and CALC.

Spectral Decomposition

A program AUTOFIT, written at Argonne National Laboratory[7] and used in the automatic decomposition of spectra from charged-particle reactions, has been adapted to run on the Berkeley 6600 system. This is an extremely flexible program, allowing the user virtually complete freedom in specifying standard peak shapes and background spectra.

PDP-9 Operating System

The PDP-9 Data Link to the 6600 is now operational. The link will permit rapid transfer of data between the two machines; it is expected that this will significantly increase the analysis rate of multidimensional data taken on-line with the PDP-9.

Fission Fragment Track Identification

The program GEM was developed to help explore the possibility of identifying fission fragment tracks in mica by using pattern-recognition techniques. The method would involve electronically scanning a mica strip and feeding the resultant data to the computer program, which would translate the information and attempt to pick out fission fragment tracks.

As now developed, GEM can recognize such tracks even when they are intermixed with a substantial amount of background.

Fission Fragment Channeling

The program TRAJ[8] has been completed. The purpose of TRAJ is to investigate the channeling of fission fragments in a uranium dioxide crystal.

Four families of graphs have been made from the calculations. The first two families relate the angular distribution for emerging fragments to initial conditions of energy, entry angle, and height above the channel axis of the fragment in the channel. The second two families of graphs relate the energy distribution of the emerging fragment as a function of the crystal thickness and of the entry angle to the channel axis.

An immediate conclusion from the data is that there is an angle, smaller than the critical angle for channeling, above which channeled fragments lose energy more quickly than unchanneled fragments.

Nuclear Theory: Inelastic Effects in Stripping Reactions

Some nuclear levels produced in (d, p) reactions having a fraction of parentage based on an excited state of the target can be produced through a process that involves the inelastic excitation of the parent following by the stripping reaction, or vice versa. If this second-order process competes with the direct deposit of the neutron onto the target ground state, then conclusions about the so-called spectroscopic factor of such a state, which are based on a first-order treatment, will be wrong. So far these effects have not been properly evaluated. The purpose of this programming

project is to theoretically evaluate the importance of this effect in a model shorn of all but the essential features relevant to this question. If it is found, as expected for some cases, that the effect is significant, a full program incorporating all the necessary features to treat realistic experimental results will be prepared.

1. PDSR, UCRL-18619, Nov. 1968, p. 97.
2. PDSR, UCRL-18877, May 1969, p. 77.
3. PDSR, UCRL-18877, May 1969, p. 78.
4. J. O. Radeloff, System Operation of the PDP-7 Computers at LRL Berkeley, UCRL-18883, May 1969.
5. PDSR, UCRL-17282, Nov. 1966, p. 29.
6. PDSR, UCRL-18619, Nov. 1968, p. 99.
7. Paulette Spink and John R. Erskine, Physics Division Informal Reports, PHY-1965 B (Argonne National Laboratory), Dec. 1965.
8. PDSR, UCRL-18877, May 1969, p. 78.

C. ACCELERATOR AND MAGNET DESIGN

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

Magnet Design

Work on the simulation of the Livermore ASTRON accelerator on the CDC 6600 has started. The project will provide interactive access to the computer via CRT display and teletype, and allow the user to adjust various model parameters.

A new program, VSPGOC, has been completed; it allows the user to introduce perturbations on a magnetic field, trace orbits through this field, and produce isoaberration plots. VSPGOC has been used successfully for spectrometer design. Program FIELD has been written to do interpolation on magnetic field data. The program assumes that the vertical component of the field has been measured at four levels, including the median plane. The measured grid at each level is assumed to be rectangular.

Orbit Studies

Program MAGOP[1] calculates the orbit of a charged particle in the median plane of a symmetric magnetic field and determines first-order horizontal and vertical transfer matrices associated with the orbit. This program is operational.

Program GOC,[2] a general orbit code for calculating cyclotron orbits, was written and revised to include the addition of arbitrary field regions in the cyclotron field. This addition allows the user to superimpose quadrupole fields on the main cyclotron field at any position and with any shape.

Program TRACE,[3] a beam-transport design program, has been modified to include second-order effects.

Cyclotron Design

Several programs (as follows) have been written to calculate various parameters used in cyclotron design.

Program RPHAZ reads data pertaining to initial conditions of particles injected into the 184-inch cyclotron and produces CalComp or CRT plots of the vertical phase-space motion and of the vertical and radial motion versus azimuthal angle.

Program TBETA allows the user to obtain radial betatron phase-space plots on a fixed length or infinite boundary. The plots may be made on either CalComp or CRT devices.

CYDE,[4] a cyclotron design code, is currently being revised to (a) reduce core size to approximately 60 K; (b) increase its usefulness and generality by adapting it to any type of cyclotron; and (c) improve some of the algorithms.

ERA

Work has continued on improving the computer model OPERA[5] to include the dynamics of extraction of an electron ring loaded with ions in a pulsed magnetic field produced by any array of coils. This program has been expanded to include the effect of the presence of eddy currents in the coils and to do extensive computations of field parameters, ion-loading formulae, and post-spillout ring motion.

To facilitate computations at the site of the experiment, a remote computer terminal

has been established at Livermore. It is connected to the Computer Center in Berkeley. The terminal consists of a PDP-8 computer with a 611 Tektronix Memory Scope and teletype. It is connected to a CDC 6600 through acoustic couplers.

Program BLOWUP[6] has been written to study the application of the beam-envelope theory of Kapchinskij and Vladimirskij[7] to a circular drifting relativistic beam focused by thin lenses.

Program TRIP was developed to calculate the beam loading for a ring charge in an arbitrary, cylindrically symmetric structure. This structure is assumed to be perfectly conducting, but may contain regions of dielectric material. The program uses a finite-difference scheme to solve the wave equation subject to a boundary condition of the third kind.[8]

Program MAFCO III[9] has been completed. It is now able to handle electron rings whose positions, as well as currents and charges, vary with time. An on-line interactive version of this program is under development.

1. MAGOP Writeup available from J. V. Lawrence, Computer Center Library, Building 50B, Room 1237A.
2. PDSR, UCRL-11776, Nov. 1964, p. 29.
3. John S. Colonias, TRACE: An On-Line Beam Transport Design Program, UCRL-18816, Jan. 31, 1969.
4. Elon Close, CYDE--A Collection of FII Cyclotron Development Codes for Use on the IBM 7094, UCID-2869, Jan. 1967.
5. PDSR, UCRL-18877, May 1969, p. 80.
6. A. A. Garren, Thin-Lens Optics With Space Charge, UCRL-19313, Aug. 1969.
7. I. M. Kapchinskij and V. V. Vladimirskij, Limitations of Proton Beam Currents in a Strong-Focusing Linear Accelerator Associated With the Beam Space Charge, in Proceedings of the International Conference on High-Energy Accelerators and Instrumentation, CERN, 1959, p. 274.
8. Steven Sackett, Calculation of Beam Loading for a Ring Charge in an Arbitrary Cylindrically Symmetric Structure, UCRL-19371 (in preparation).
9. PDSR, UCRL-18877, May 1969, p. 79.

D. BIOMEDICAL APPLICATIONS

Robert Fink, Deanna Harrell, Cheryl Herrin, William Hogan, Mark Horovitz, Martin Itkowitz, Claudette Rugge, Marjory Simmons, Kenneth Wiley, and Edna Williams

For Laboratory of Chemical Biodynamics

The ACQUIRE data-acquisition system[1] utilizes a Sigma 2 and a PDP-8L computer. These computers have been delivered; the Sigma 2 is now undergoing acceptance tests. The RBM Monitor System for the Sigma 2 will provide a framework for our software. Specification and preliminary design of additional systems and utility routines necessary for ACQUIRE have been carried out. Detailed information on the system will be published in a series of ACQUIRE Notes and Newsletters.[2]

A preliminary handbook[3] for the PDP-8 NMR data collection system was written. Recent additions to this system include provision for complete disk and tape library and loading facilities, CalComp plots, and a program to utilize newly designed hardware. This additional equipment consists of a four-channel ADC with external adder and data-break facilities.

Spectra collected via the PDP-8 can be processed by the 6600 program FORTE. This routine accepts input either in the form of punched cards or magnetic tape of the format produced by the PDP-8. The program can carry out the following operations on the input spectra: normalization, filtering, integration, and calculation of Fourier transforms. Output options include printed tables, printer plots, and CalComp plots.

Least-squares fitting programs used for spectral decomposition have been improved. Program FELSPAR[4] was modified; one new version includes the CalComp routine SPLOT;[5] the photoelectron calibration procedure was deleted in another version named GENSPAR.

Work has started on the latest program in this series. This program, SUNDER, incorporates improvements giving increased processing speed and a wider choice of calibration spectra, and of input and output options; it also accommodates a variable number of fitting parameters. These programs can be applied to the analysis of data from both Nuclear Chemistry and Chemical Biodynamics Laboratory experiments.

The PDP-8 program ISOTOX,[6] which analyzes isotope data from a well counter, has been revised to accommodate recent changes in the data-collection equipment.

1. Robert Fink, ACQUIRE-A Data Acquisition and Analysis System for the Laboratory of Chemical Biodynamics, Sept. 3, 1969.
2. Robert Fink and Martin S. Itzkowitz, ACQUIRE Progress Report #1, Oct. 30, 1969.
3. Kenneth G. Wiley, NMR Data Collection System Handbook (Preliminary Version), UCID-3390, Sept. 1969.
4. PDSR, UCRL-17876, Nov. 1967, p. 54.
5. PDSR, UCRL-18877, May 1969, p. 82.
6. PDSR, UCRL-18619, Nov. 1968, p. 101.

For Health Physics

Program BADGE,[1] which adds and updates γ and neutron radiation records for all LRL Berkeley employees, has been completed and is in routine use.

TELLY[2] is a VISTA display program that accepts on-line modification of neutron flux data. Spectra computed from this input can be displayed immediately. Recent changes have made this program easier to use and have provided more options in the graphing procedure.

The 6600 program ASOCH was written to produce an ordered list of the energies and intensities of γ rays associated with all known radioactive isotopes.

1. PDSR, UCRL-18877, May 1969, p. 81.
2. PDSR, UCRL-17544, May 1967, p. 41.

For Medical Services

ASTEAM, a 6600 Fortran program, which plots graphs of radiation penetration depths in research animals, has been modified to permit background data to be subtracted from sample values.

For Biomedical Research

A 6600 program GODNA was written. It converts scintillation-counter measurements of DNA in a density gradient into area-normalized distributions and produces CalComp plots of these.

The 6600 program TDFFT[1] comprises a group of subroutines that compute a Fourier transform of very large two-dimensional complex arrays. These routines will transform up to 2^{20} complex points. TDFFT was completed and submitted to the 6600 Program Library.

Correlation matrices produced from genetic data by the program FLYS[2] were subjected to a modified principal-components analysis using program PRCMPS. The interpretation of the results was prepared for publication.[3]

MEDPIC[4] was used to produce comprehensive pretreatment and posttreatment summaries for the group of diabetic retinopathy patients treated at the Donner Pavilion; similar summaries were prepared for the follow-up group. The results, and a discussion of the project, were written up for inclusion in the Spring 1970 Biology and Medicine Semiannual Report.[5]

MEDPIC was converted to simple blocked binary I/O. The new version uses fast ASCENTF blocked binary read-and-write routines instead of formatted READ's and WRITE's. Adaptable versions of these subroutines will be available in the Library.

A series of 6600 programs was produced to aid a study using radioactive labeling of human blood platelets. The programs were named BLOOD, NEWREG, LSQREG, EXPREG, POLYREG, REGRES, SMSPL1, BARLOW, and CONCAT. Experimental data were fitted with polynomials or sums of

exponential functions. The mean life span of the platelets was computed together with various statistics. CalComp plots of various functions were produced. A test program, PAULUS, generated artificial data that included the simulation of experimental errors.

A new program, PLOT3D, was completed and submitted to the 6600 Library. This program generates a perspective view of single-valued functions of two variables. Hidden lines are not eliminated in this version. Programs PLFIL and PLTR use PLOT3D to produce CalComp displays of the Fourier transform of two-dimensional complex arrays. The transforms are computed by use of program TDFFT.

Program MEDPLOT sorts two-dimensional arrays in order of increasing X and Y values. It then adds groups of columns (X) and rows (Y) together to reduce the dimensions of the array. The contents of this smaller array are plotted in perspective by use of routine PLOT3D.

1. PDSR, UCRL-18877, May 1969, p. 81. Also available in the 6600 Program Library.
2. PDSR, UCRL-18877, May 1969, p. 102.
3. Collin Murphy and Chiyoko Tokunaga with the collaboration of W. Hogan, Cell Lineage in the Dorsal Mesothoracic Disc of Drosophila (UCRL-19285, Aug. 1969), submitted to Archiv für Entwicklungsmechanik der Organismen, Wilhelm Roux'.
4. PDSR, UCRL-18619, Nov. 1968, p. 102.
5. With H. Stauffer and J. Price, Spring 1970 Biology and Medicine Semiannual Report (in preparation).

E. MISCELLANEOUS

Robert Belshe, Mansfield Clinnick, Deanna Harrell, David Jensen, James Miller, and Bobby Powell

Bevatron

Bevatron External Proton Beam Control

A major revision to this program[1] was made to provide perturbations in the current in any magnet, with the perturbation time and width being determined by the program rather than by external hardware. The numbers of magnets under control of this system was increased to 20.

Bevatron Main Motor Generator Control

A program BMAG, to replace the Bevatron MG pulser with a PDP-8, has been written, and was put into continuous use on October 1. This routine has three major parts:

(a) The Pulser--this section of the program controls the rectification-flattop-inversion cycle of the main motor generators and provides continuous error monitoring.

(b) The Profile Library--this section stores, reads, punches, and analyzes a number of different magnet current profiles.

(c) The Startup Routine--this section selects a profile from the library, analyzes it for a number of illegal conditions, and puts it into operation.

1. PDSR, UCRL-18877, May 1969, p. 82.

Utility Programs

PDP-9 Assembler

A PDP-9 assembler running on the 6600 is completed and documented. This assembler uses a field-free format similar to COMPASS. It has the capability of producing binary output on paper tape or magnetic tape in a large number of different formats for the numerous types of loaders in use. It was written in the BLIMP language,[1] using PROMAC,[2] and is capable of handling 400 cards/sec in 35 K of core.

PDP-8 Disk Library

The disk portion of the new PDP-8 Disk Library was rewritten to operate with the Berkeley Scientific disk, which is now in use at the Bevatron.

GERBER Plotting

GERBER is a 6600 plotting routine package used for generating paper-tape output for a 60×90-inch drafting board and picture-taking facilities.

1. PDSR, UCRL-17876, Nov. 1967, p. 59.
2. PDSR, UCRL-18619, Nov. 1968, p. 105.

II. SYSTEMS PROGRAMMING

Eric Beals, William Benson, Jerry Borges, Douglas Brainard, James Burkhard,* Roy Carlson, Mansfield Clinnick, Robert Fink, Richard Friedman, William Gage, Nigel Harrison, Walter Hutchinson, Joyce Johnston,† Jeremy Knight, Michael Long, Samuel Penny, Gregory Richterich,† Edward Romascan,* David Stevens, and Donald Zurlinden

ASOP (The 6411 Systems) (Ref. 1)

Disk handling was modified to provide increased reliability. An effort to improve system documentation was begun.

BKY (The 6600 System)

The disposition of the seven projects listed in the preceding Semiannual Report[2] as "in progress or planned" is as follows.

(a) Automatic accounting of RUSH and PRIORITY time: completed.

(b) Dynamic resident peripheral library: completed.

(c) Many control points: design is essentially complete and implementation has begun.

(d) Major reworking of I/O: scaled down to a minor effort which is now in an early design stage.

(e) Examination of Fortran mathematical routines: completed.

(f) Installation of the CDC CP loader: abandoned, at least until the major bugs are removed.

(g) Mechanism to permit CHIPPEWA main programs to call SCOPE subroutines: postponed indefinitely.

The BKY CP loader, LODER, was extended to handle absolute overlays. New, more reliable tape error-handling routines were designed and installed. A procedure to automate the paging of tapes from the tape vault has been designed and coded; it will be installed when the RECC (Remote Equipment Control Computer) system becomes operational.

MSS (The Mass Storage System) and PSS (the Program Storage System)

Both MSS and PSS have become operational and are seeing increasing usage. An effort is under way to unify, insofar as possible, the control languages of the two systems. The data cell diagnostic program, DCT,[3] has been completed. New disk pack accessing methods are being designed to increase system reliability.

Utilities

A public documentation library, called WRITEUPS, has been established in PSS. It is designed to encourage up-to-date documentation of developing systems. At present, it contains write-ups for MSS, PSS, BARB, and DMPS, and BKY System Change Notes.

A general-purpose COPY program containing file and record-merge options was introduced.

The formatting program BARB for preparing and updating WRITEUPS documentation was developed.

A new, more readable octal dump program, DMPS, suitable for use with SCOPE-style jobs, was introduced.

COPYCL was provided to implement the COBOL verbs INCLUDE and COPY.

The Fortran source-language debugging routine TRACK was provided, together with a tutorial program (DISPLAY).

Interactive Applications

A new editor for BRF[4] was written and debugged. It uses an explicit sequence number stored as a part of each line for line identification. The text in the buffer is linked by forward and backward pointers to facilitate easy insertion and deletion of lines. The editor includes facilities for automatically generating the sequence numbers as an option, for converting the text from a field-free form to standard fixed-field Fortran form, for resequencing the text, and for paper tape

input and output.

A complete set of matrix operations, including inversion, was added to BRF, as were job-initiation facilities and the ability to reference PSS files.

An output scanning package utilizing the 250 consoles is in the final stages of design, and coding has begun.

RECC (Remote Equipment Control Computer)

RECC is a PDP-8/L with a large disk; its purpose is to permit flexible expansion of our teletype capability. The computer and the disk have been delivered. The hardware interface to the 6600-series computers is being designed and built at LRL: it is nearly ready for debugging. The basic system software has been designed and coded, and debugging has begun.

Computer Acquisition

In preparation for the possible acquisition of a large-scale computer, two continuing projects have been initiated: a series of informal seminars on possible systems designed for the resulting computer complex, and an effort to collect accurate data on the current computing load. In addition, investigations relative to the implementation of remote batch and virtual output facilities have begun.

*Group A Programming personnel.
†CDC Programming personnel.
1. Sam Penny, ASOP: Attached Support Operation System, Mathematics and Computing Memo No. 303, Nov. 1967, available in the Computer Center Library.
2. PDSR, UCRL-18877, May 1969, p. 84.
3. PDSR, UCRL-18877, May 1969, p. 84
4. J. Burkhard and E. Romascan (Members of the Group A Programming Staff), The Berkeley Remote Facility (BRF) User's Guide (Version 1), UCID-3339, June 3, 1969 (available from J. V. Lawrence, Computer Center Library).

III. COMPUTER OPERATIONS

F. Marvin Atchley and Paul A. Rhodes

The Input/Output area was reconfigured in May, allowing increased space for the high-speed printers and a more efficient system of output distribution. An additional card reader for 6600 input was installed in this area, thereby increasing self-service capacity and reducing the handling of input decks by operators.

A PDP-8/L computer, to be used as a remote equipment control computer (RECC), was installed in July.

A rapid film processor which permits test viewing of the CDC-254 Microfilm Recorder output was installed in Building 50. A new Xerox printer, which produces high-quality prints from microfilm, was installed in late October.

A new procedure for the rapid mounting of frequently used magnetic tapes has been implemented.

Hardware switches allowing the switching of all printers between the 6411 and 6600 have been installed.

IV. RESEARCH IN MATHEMATICS AND COMPUTER SCIENCE

Paul Concus, Mark Horovitz, David Jenson, Loren Meissner, Grove Nooney, and Jonathan Young

Surfaces of Linearly Varying Mean Curvature

Investigation continues 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 at fixed angle.[1] For a cylinder whose cross section contains a corner, the explicit asymptotic form of the surface in the neighborhood of the corner has been obtained.[2] The analytic study of the case of a noncircular cylinder with smooth boundaries is nearly completed, and a numerical technique is being developed to confirm and complement the analytic results.

Spline Functions

A generalized formulation was published for spline functions of the third order.[3]

Data Acquisition

A PDP-5 program MUON has been written for data acquisition in the experiment currently being conducted by the University of Washington and the Crowe Group at the 184-inch cyclotron. This program collects events, writes them on tape, and forms histograms of the data. The histograms may be printed on the teletype or displayed on the on-line CRT, or both.

A PDP-5 program, PHA, that accumulates 16 K channels of histogram on a movable-head Data Disc M6 disk on a continuous basis at the rate of 750 events per second has been completed. A paper based on this project, and other experiences with accumulating histograms on a disk and with projected data rates for a fixed-head disk, is in preparation for presentation at DECUS.[1]

1. David W. Jenson, Some Experiences with Pulse Height Analysis Using a Disk (UCRL-19402, Nov. 1969), in Proceedings of the Digital Equipment Computer Users' Conference (DECUS), November 1969 (to be published).

Typesetting

The CDC 6600 FORTRAN program TYPS[1] was completed. TYPS (for typesetting) accepts as input a 12-bit character string and produces a magnetic tape for use in controlling a Linofilm typesetting machine. TYPS was used in production of the index for the IMRD Annual Report.

The PDP-8 program RKDS was written. RKDS generates 12-bit character strings and, when complete, will provide input for programs such as TYPS.

1. PDSR, UCRL-18877, May 1969, p. 86.

Shop Effort

SHUFL is a third and final version of the shop and engineer effort-projection programs written during the previous year.[1,2] The shop-estimated man-hour projections and the simulated engineer man-hour projections have been further broken down to show effort expected on individual physics, chemistry, and biology experiments and also work expected on outside projects.

1. PDSR, UCRL-18619, Nov. 1968, p. 103.
2. PDSR, UCRL-18877, May 1969, p. 83.

Printed-Circuit Artwork

Major effort on PUZZLE,[1] a program to aid in the design of printed-circuit cards, has been directed to merging the VISTA input system with the production program. Effort has been spent to revamp the routing algorithms to handle the denser boards necessitated by dual in-line packages and double-sided connectors.

1. Deanna A. Wilber Harrell and Ronald Zane, Computer-Aided Design of Printed-Circuit Artwork, UCRL-18172, April 1968.

Information Processing

The new program KWIC was written to search out significant words from strings of text or titles and form an index. The program is also used for searching data (such as descriptive abstracts of papers) by use of specified search words.

The ARDIE System for the CDC 6600 includes a special library of nine programs. These programs are called in varying sequences by different control-card decks to provide text output in various forms (Linofilm, photocomposer, CRT film, CalComp plotter, and printer). The ARDIE System allows the nonprogramming user to obtain his results (such as publication indexes, author title searches, archival listings, etc.) through use of data-card options, thus minimizing use of programming manpower and increasing user convenience.

Theoretical Biology

A mechanism relating growth and differentiation of cells is under study. The proposed model assumes that, for the protein-synthesizing machinery of a cell, competition occurs between two classes of messenger RNA: mRNA coding for differentiated cell components competes with mRNA required for normal cell growth and maintenance. A comparison between qualitative features of this model and experimental data was presented at the Third International Biophysics Congress.[4]

Epidemiology

Mortality data show that the leukemia associated with pregnancy is chronic myeloid in Japan and chronic lymphatic in England and Wales.[5]

Crystallography

Using Fejér means in the Fourier synthesis of electron-density functions ensures that the functions be nonnegative and gives a method for approximate solution of the phase problem.

PDP-8/I Time Sharing

A time-sharing monitor and a simple file system are operational, allowing work to proceed on interactive programs to run under the system. A rough simulation of the monitor indicates that the system could support approximately 30 users and still maintain 1-sec respone times for all requests involving less than 30 msec of computer time (this would include almost all editing tasks). The multi-computer configuration will help reduce response time for requests involving heavy computational loads.

Prototype Technical Text Entry Station (PDP-8)

The objective of this project is to assemble a prototype low-cost entry station for technical text, centered in a small computer and furnished with keyboards, CRT displays, and hard-copy facility.

The keyboards are obtained commercially, but are arranged and coded to our specification, and all are provided with 69 or more "character" keys, plus shift and other font-selection controls.

The CRT display consists of a storage scope. It is used for drawing the characters of the text string which the computer generates as it decodes the input coming from the keyboard.

The proposed hard-copy facility consists of a facsimile recorder that is used principally for producing proof copy intended for further "off-line" perusal and detection of errors, and changes for later entry.

The small computer in the prototype system now being assembled is provided with a disk memory to allow the storage of longer text strings and larger character repertories than could be accommodated directly in core. It also has an output channel in the form of a reasonably high-speed teletype line or in the form of a magnetic tape drive; this will permit it to produce text strings for high-quality photocomposition or for entry into an information-retrieval system, for example.

All the hardware, except the facsimile recorder and the output channel, have been assembled. Programs are operational for accepting input from the keyboard and concurrently displaying it on the Storage Scope. Programs for emending text are partially complete. Preliminary planning has been completed for the facsimile recorder and the output channel.

1. PDSR, UCRL-18877, May 1969, p. 85.
2. Paul Concus and Robert Finn, On a Class of Capillary Surfaces, J. Analyse Math. (to be published).
3. Jonathan D. Young, Generalization of Segmented Spline Fitting of Third Order, Logistics Rev. 5, 33-40 (1969).
4. Mark W. Horovitz, A Model Relating Growth and Differentiation by Competitive Subcellular Process, in Proceedings of the Third International Biophysics Congress, August 1969.
5. Grove C. Nooney, Normal Leukopoietic Stress and Leukemia (UCRL-18888, May 15, 1969), submitted to J. U. S. Natl. Cancer Inst.

V. PUBLICATIONS

1. J. Burkhard and E. Romascan, The Berkeley Remote Facility (BRF) User's Guide (Version 1), UCID-3339, June 3, 1969.

2. W. R. Butler, D. G. Coyne, G. Goldhaber, B. H. Hall, J. N. MacNaughton, and G. H. Trilling, The ϕ/ω and η/η' Production Ratios in the Reaction $\pi^+p \rightarrow \Delta^{++}$ + Boson at 3.7 GeV/c (UCRL-19225, June 1969), presented at the Lund International Conference on Elementary Particles, Lund, Sweden, June 25–July 1, 1969.

3. Elon Close, FORTRAN Input/Output à la ALGOL: A Set of FORTRAN Routines Patterned After Their ALGOL Equivalent, UCID-3369, July 16, 1969.

4. Paul Concus and Robert Finn, On A Class of Capillary Surfaces (UCRL-19219), May 1969), submitted to J. Analyse Math.

5. Paul Concus and Robert Finn, On the Behavior of a Capillary Surface in a Wedge, Proc. Natl. Acad. Sci. U. S. 63, 292-99 (1969).

6. G. Goldhaber, W. R. Butler, D. G. Coyne, B. H. Hall, J. N. MacNaughton, and G. H. Trilling, The $\omega\rho^0$ Interference Effect (UCRL-18894, June 1969), presented at the Conference on π and $K\pi$ Interactions, Argonne National Laboratory, May 14-16, 1969; also, submitted to Lund International Conference on Elementary Particles, June 25-July 1, 1969, Lund, Sweden.

7. G. Goldhaber, W. R. Butler, D. G. Coyne, B. H. Hall, J. N. MacNaughton, and G. H. Trilling, Further Study of the H(990) Effect (UCRL-19229, June 1969), contributed to Lund International Conference on Elementary Particles, June 25–July 1, 1969, Lund, Sweden.

8. ——, The $\omega\rho^0$ Interference Effect in the $\pi^+p \rightarrow \pi^+\pi^-\Delta^{++}$ Interaction (UCRL-19352, Sept. 1969), submitted to Phys. Rev. Letters.

9. B. H. Hall, R. W. Bland, G. Goldhaber, and G. H. Trilling, Partial-Wave Analysis of K^+p Elastic Scattering (UCRL-19231, July 1969), presented at the Lund International Conference on Elementary Particles, June 25–July 1, 1969, Lund, Sweden

10. Mark W. Horovitz, A Model Relating Growth and Differentiation by a Competitive Subcellular Process (UCRL-19202–Abstract, May 1969), presented at the Third International Biophysics Congress, August 29-September 3, 1969, Cambridge, Mass.

11. Collin Murphy and Chiyoko Tokunaga, with the collaboration of W. Hogan, Cell Lineage in the Dorsal Mesothoracic Disc of Drosophila (UCRL-19285, Aug. 1969), submitted to Archiv für Entwicklungsmechanik der Organismen, Wilhelm Roux'.

12. Grove C. Nooney, Normal Leukopoietic Stress and Leukemia, UCRL-1888, May 15, 1969, submitted to J. U. S. Natl. Cancer Inst.

13. S. Sackett, Solution of the Magnetostatic Problem in Three Dimensions, Preliminary Investigations at LRL, Berkeley, UCID-3335, May 1969.

14. Steven J. Sackett, Application of the Monte Carlo Method to the Solution of LaPlace's Equation in Three Space Dimensions, UCID-3338, Aug. 1968 (issued Sept. 1969).

15. Kenneth G. Wiley, NMR Data Collection System Handbook (Preliminary Version), UCID-3390, Sept. 1969.

DATA HANDLING

Howard S. White in charge

Compiled and edited by Dennis Hall and Shirley Buckman

Group effort was divided into three general areas:

1. Development of a fully automatic scanning and measurement system for bubble chambers (DAPR).
2. Refinement of the existing systems to improve flexibility and efficiency (HAZE, FOG, CLOUDY, FAIR, and Event Accounting).
3. Continued operation of the existing systems to produce physics results.

Although the main development emphasis was on the DAPR system, much of the group's effort was expended in making the many small adjustments required to initiate and maintain the processing of new physics experiments. The rough design specifications for the tandem FSD systems were also completed during this period.

DEVELOPMENT OF NEW SYSTEMS

DAPR: Fully Automatic Scanning and Measurement

By the end of October, preparations for processing a large comparison experiment were nearly complete. The computer operators were trained to run the new system, and final debugging of the operating system was completed. Unfortunately, a significant amount of time in July and August was spent detecting and correcting a computer malfunction which prevented the DAPR system, with its heavy use of the disk, from operating for more than about 40 minutes between breakdowns. Some of the more significant program improvements to the DAPR system are discussed below.

Program 511: Track Following (Joan Franz)

Constants for the LRL 25-inch bubble chamber and the SLAC 80-inch bubble chamber were assembled and debugged. The beam parameters for both chambers were carefully optimized to ensure following the maximum number of beam tracks in the beam mode.

Several modifications were made which improve the quality of the non-beam track-following routines. First the ability to quickly detect the beginning of a real track segment together with the consequent detection of spurious digitizings simulating tracks was implemented. This resulted in a more economical, higher-fidelity detection of non-beam tracks (initiation). Second, it was possible to use a finer mesh (2μ) in the actual track following. This allowed narrower road widths to be used, resulting in less confusion in regions of crossing tracks, as well as a more sensitive detection of small-angle scatterings. Finally, research into improved track-following algorithms was started, but it was set aside in order to get more experience with the existing algorithms.

Two operational changes were also implemented in program 511. First, the ability to preselect the frames to be measured was debugged. This feature is desirable for use with low-yield film, since only frames that contain events are measured. Second, the

operator communication panel on the FSD was implemented so that processing can be more effectively monitored from the FSD itself.

Program 513: Vertex Search--Track Match (Howard White and Dennis Hall)

The ability to delete "interloper" non-beam tracks was added. Most of these tracks fall into two categories: Tracks that pass near the vertex in space but do not participate in the event, and tracks that participate in another event, but extrapolate to the event in question. Deletion of these tracks produced a significant improvement in the throughput of the DAPR system.

In addition to the above changes, the entire track-match cleanup section was redesigned. (These changes will be discussed in more detail in the next report.) Preliminary results indicate that perhaps one half of the remaining failures will be recovered by the new procedure.

Program 516: Automatic Scanning (Joan Franz and Barbara Britton)

Scanning instructions for the 25-inch and 80-inch chambers were written and debugged. Small but important changes to the event-reporting section were made which allow a more complete analysis of the scanning throughput.

Program 517: DAPR Tape Merge (Wen-Sue Gee)

The ability to select events from a DAT (Data Abstract Tape) by using a FAIR selection tape was added. This allows all events in a given category to be collected on one tape for further study. This ability is of particular value in studying events that fail.

Program 518: CalComp Display Program (Barbara Britton)

This program was generalized to input HAZE library tapes as well as DAT library tapes.

Program 519: Fixed Noise Detection (Wen-Sue Gee)

The ability to output punched cards for direct input to program 512 was added, as well as a CalComp plot that displays all the fixed noise by view and sweep.

Program 520: Track Comparison (Wen-Sue Gee)

This program compares two independent measurements of the same track by computing a least-squares circle or a higher-order fit to the two measurements. Debugging of this program continued.

Program 521: Track Comparison Display (Joan Franz)

Debugging of this program, which displays the results of program 520, was completed.

Program 522: HAZE Library to DAT Library Conversion (Shirley Buckman)

Program 522 provides the final link for comparing DAPR measurements with measurements from other systems. This program converts a tape in the HAZE library format to DAT library format. This allows a consistent track-numbering and particle assignment to be made by the DAPR scanner (516) to the comparison data. This program was flowcharted, coded, and debugged during this period.

Program 212: CLOUDY Library Comparison (Barbara Britton)

Although this program is a CLOUDY series program, its main use for the present will be to compare kinematical results from the HAZE and COBWEB systems with the corresponding results from DAPR. All significant kinematical quantities are differenced and output on a CLOUDY format tape. Thus large statistics can be accumulated quickly and displayed with the FAIR system of programs.

MAINTENANCE OF EXISTING SYSTEMS

Both the HAZE systems of event measurement, the FCF data-analysis systems, and the TRIST system continued to operate in routine production status. New developments to these systems were confined to improvements in operating efficiency and extending the system to include new experiments.

Some of the more significant changes are discussed below.

HAZE: Semi-Automatic Event Measurement

(Wen-Sue Gee, Loren Shalz, Jim Greene, and Priscilla Davis)

Program 440: Scan Tape Merge

The ability to write either blocked records or unblocked records under operator control was added. A new vertex calculation which allows a more accurate event match in the Event Accounting Programs was also added.

Program 441: Scan Tape Edit

This program, which provides image-plane digitizer (SPV-B) track measurements to the Segrè-Chamberlain Group, was modified to provide standard corrections for the more common scanning errors.

Program 434: FSD Calibration

The ability to control FSD stage speed and slit density from the 7094 operator's console was added.

FCF: Geometry, Kinematics, Data Display

Loren Shalz, Shirley Buckman, Vivian Morgan, Michael Block, and Barbara Britton

Program 140: Three-View Geometry

Modifications were added so the program can recognize and handle data produced by DAPR, and a new vertex calculation based on the method used by DAPR was added.

Program 211: CLOUDY Merge

This program was debugged, and put into routine production status.

Program 304: Data Abstraction

Except for minor revisions, all the flowcharting for the revised version of this program was completed, and coding of some of the subroutines was begun. The ability to process ionization information from the COBWEB system was also added.

Many special calculations were written for particular physics needs. These include: (a) The ability to cross-reference different kinematical hypotheses on two libraries. This allows afterthoughts to be added without the expense of a complete reprocessing of all the data. (b) The ionization χ^2 calculation was modified to run directly from CLOUDY input, thus avoiding having to save space on the FAIR Library for nonuseful data. (c) Particle lifetime in the center-of- mass frame, the error, and the Mandelstan variables with their errors were calculated for a two-prong experiment.

TRIST: System Monitor

Carol Osborne and Pris Davis

The ability to run simultaneously A-, B-, and C-level programs was debugged, thus allowing background calculations during DAPR processing.

Many special modifications were added to help isolate computer malfunctions. Computer failure accounted for a large expenditure of effort by the Data Handling Group for a period of approximately 1 month.

Work on an improved system update program (118) was started. This program will make more storage space available on the disk, will perform a much more thorough check of data transmission, will run faster, and will be easier to operate than the current program.

DATA PROCESSING OPERATIONS

The following table summarizes the processing of events measured on the COBWEB and HAZE 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				
28	30-inch propane/freon	Stopping K^+	Powell-Birge	948
42	72-inch HBC-LRL	1.53-1.84-GeV/c π^+p	Powell-Birge	436
43	25-inch HBC-LRL	1.53-1.84-GeV/c π^+p	Powell-Birge	396
44	25-inch HBC-LRL	1.53-1.84-GeV/c π^+p	Powell-Birge	376
46	25-inch HBC-LRL	1.53-1.84-GeV/c π^+p	Powell-Birge	16786
47	25-inch HBC-LRL	1.53-1.84-GeV/c π^+p	Powell-Birge	4 864
50	25-inch HBC-LRL	1.16-1.57-GeV/c K^-	Powell-Birge	7 728
51	25-inch HBC-LRL	1.16-1.57-GeV/c K^-	Powell-Birge	10 293
52	25-inch HBC-LRL	1.16-1.57-GeV/c K^-	Powell-Birge	13 125
		Total COBWEB measurements processed		54 952
HAZE system				
01	82-inch DBC-SLAC	12.0-GeV/c π^-	Riverside	383
43	25-inch HBC-LRL	1.53-1.84-GeV/c π^+p	Powell-Birge	575
44	25-inch HBC-LRL	1.53-1.84-GeV/c π^+p	Powell-Birge	679
45	25-inch HBC-LRL	1.53-1.84-GeV/c π^+p	Powell-Birge	84 325
48	25-inch HBC-LRL	1.53-1.84-GeV/c π^+p	Powell-Birge	36
53	25-inch HBC-LRL	1.16-1.57-GeV/c π^+p	Powell-Birge	12 526
54	25-inch HBC-LRL	1.16-1.57-GeV/c π^+p	Powell-Birge	44 044
71	72-inch DBC-LRL	6.0-GeV/c p	Segrè-Chamberlain	283
72	80-inch DBC-BNL	8.0-GeV/c p	Segrè-Chamberlain	14 366
91	72-inch HBC-LRL	3.5-GeV/c π^+	Trilling-Goldhaber	159
92	72-inch HBC-LRL	3.5-GeV/c π^+	Trilling-Goldhaber	84
95	82-inch DBC-SLAC	12.0-GeV/c K^+	Trilling-Goldhaber	52 657
		Total FSD measurements processed		210 117
		Total events analyzed		265 069

Accelerator Operation and Development

ACCELERATOR STUDY GROUP

Edward J. Lofgren in charge

SUPERCONDUCTIVITY

William S. Gilbert

Refrigerator-Liquefier

A "500 Inc." refrigerator-liquefier has been in routine service during the report period. The capacity of this system is 35 watts of refrigeration at 4.2° K, and a maximum production rate of 10 liters of liquid helium per hour when used as a liquefier. The system has been used in three operating modes:

(a) Producing liquid helium in a 500-liter storage Dewar.

(b) Refrigerating, in closed cycle, superconducting magnets in their Dewars.

(c) Simultaneously refrigerating a magnet in closed cycle and making liquid helium in the storage Dewar.

During the 6-month period the monthly operating (on) time, based on a 24-hour day, has ranged from 67% to 92%, with an overall average of 80%. Four repairs were required on the compressors, and three on the refrigerator.

Dipole Transport Magnets

A four-layer superconducting magnet wound saddle-shape with twisted rectangular multicore NbTi conductor was tested both with and without an iron return path. In both cases the magnet performed to the short-sample capabilities of the conductor, some 35 kG without iron, and 40 kG with. The corresponding central fields are 28 and 35 kG. The magnet has a 4-in. bore and an overall length of 16 in. The total stored energy is 25 to 30 kJ. See Fig. 1.

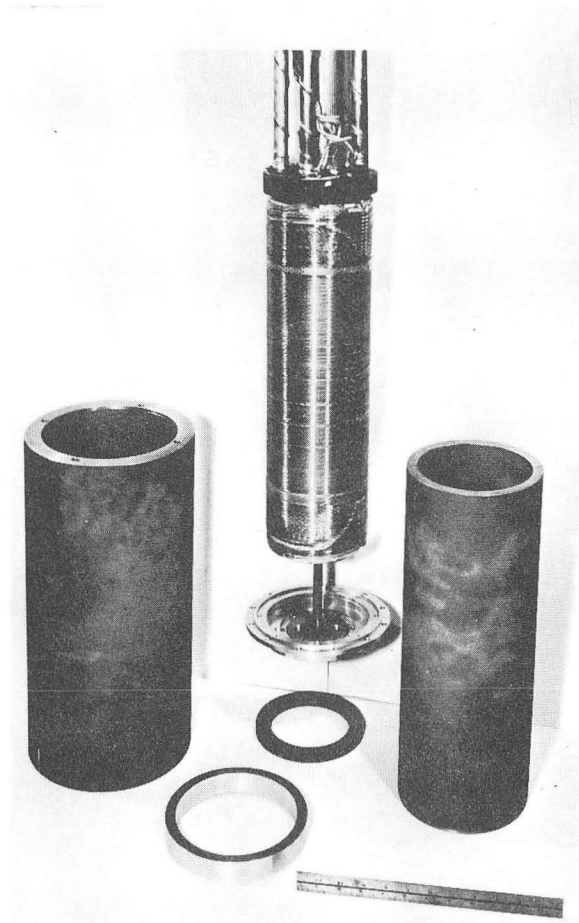

Fig. 1. Superconducting magnet disassembled to show core.

A larger bending magnet has been wound with untwisted rectangular conductor. The bore is 6.5 in., the length is 3 ft, and eight layers of conductor are used. The magnet has been tested with two layers, four layers, and six layers. In all cases the magnet has shown degraded performance, i. e., the transition currents have been below the material

short-sample characteristics. This is attributed to the instabilities associated with the untwisted conductor.

Quadrupole Transport Magnets

A small square quadrupole magnet with 1.25-in. bore and some 10 in. long was wound with untwisted multicore rectangular conductor. This magnet had a degraded performance which we associated with the instabilities of the untwisted conductor.

The magnet was rewound with twisted conductor and achieved transition currents more than twice as high as with the untwisted material (1500 A vs 700 A). The transition current was effectively short-sample performance for the twisted conductor.

Stability and Loss Studies

Losses in superconductors under pulsed conditions have been studied for various combinations of filament size, matrix size, and twist rates in multicore conductors.[1] Losses and stability have been measured through magnetization loop area and flux-jump sensitivity techniques. We have now correlated the magnet degradation data with the more fundamental stability behavior of the superconductor.

1. William S. Gilbert, Robert B. Meuser, and Ferd Voelker, Losses in Pulsed Superconducting Magnets (UCRL-18885, Aug. 1969). Presented at VII International Conference on High Energy Accelerators, Yerevan, USSR, August 27-Sept. 2, 1969.

ELECTRON RING ACCELERATOR PROGRAM

Walton A. Perkins

Introduction

During this 6-month period effort was centered on Compressor III and injector facility to be built in Berkeley. The Compressor III effort had three phases: (a) construction and assembly before the August experimental run; (b) the 3-week experimental run in August; (c) modifications, repairs, and improvements between runs.

A model pulsed acceleration cavity for the new electron injector facility was tested. The results were very encouraging, and five acceleration cavities are being constructed. The tunnel and experimental building are now under construction and should be completed in the early spring of 1970.

Several members of the ERA Group attended the VII International Conference on High Energy Accelerators at Yerevan, Armenia, USSR. They presented five papers (three on ERA).

Compressor III--Before the August Run

The large solenoid-type coils for the final compression and extraction were completed early in this period. Trim coils to create a more uniform field region for accelerating ions were designed and built.

A liquid-helium-cooled finger for cryopumping was constructed and installed. The surface area is 300 cm^2, and the pumping speed about 3000 ℓ/sec. Baking and use of liquid helium produced pressures in the low 10^{-9}-torr region in a test chamber. We hope to achieve such pressure during the run with all the probes, etc., in the vacuum chamber.

Movable probes were constructed and installed; four enter the compressor through the left end, three through the right end, and three enter radially in the central region. All the probes can be positioned remotely with the beam on and the machine pulsing.

The inflector coil structure was redesigned and rebuilt to move some of the current element outside the vacuum chamber so that the interior as seen by the beam is more nearly symmetric.

It was decided to design and build an image cylinder because: (a) calculations showed that axial ion focusing of the ring (during rollout and spillout) was small for ion loading of only a few percent, and (b) if the background gas pressure was low enough, crossing of the radial integral resonance (which could increase the minor dimensions

of the ring) could be avoided with an image cylinder. A dielectric cylinder was designed to be placed within the ring. This provides electric images, but not magnetic images, thereby producing the required focusing. Because of problems in delivery of the alumina cylinder, we used a quartz tube that was filled with titanium dioxide, which has a high dielectric constant.

Early in the summer the compression coils were set up at Berkeley for magnetic field measurements. A group of three small search coils (mounted on a precision radial arm and variable in the cylindrical coordinates r, θ, and z) was used to probe the field. The position of the "median plane" as a function of radius was measured and found to be satisfactory. The perturbation of the field due to the iron injection snout was also judged to be acceptable. The variation of the radial component of magnetic field within the solenoid, which is the quantity that directly determines the acceleration of the ring and the ions contained within, was measured carefully, and a set of monitor loop was calibrated. One disturbing result of these magnetic measurements was the finding that eddy-current effects in the body of the copper of adjacent--but unshorted--coils were more significant than had been previously thought. In particular, the way in which the field index, $n = -\frac{R}{B}\frac{dB}{dR}$, varied with radius was markedly different from that calculated in programs neglecting eddy currents. The situation was improved by shimming the coils to different axial positions and by varying the voltages and triggering times. Of most significance, however, was the development--as a result of these experimental measurements--of an improved computer code in which the dominant effects of eddy currents were included. The code was used during the run to determine the n trajectory of the ring via a teletype facility at the experimental site in Livermore.

Compressor III--August Run

The run commenced on August 2 and ended on August 24. Most of the first 2 weeks was spent installing and connecting the beam line and compressor with a careful checkout of coils, probes, etc. Figure 2 shows Compressor III as assembled (in Berkeley for installation at Livermore). During the last week, rings were formed of about the same intensity as in the Compressor II run, and some preliminary extraction tests were made.

Injection was similar to the Compressor II run with a trapped circulating current of about 100 A (2.5×10^{12} electrons). Self-trapping of the electron ring was observed again, and for most of the run the inflector was turned off, as the self-trapping resulted in more consistent operation.

With the better n trajectory determined by computer calculations, coil placement to achieve the calculated trajectory, coil design to eliminate the first-harmonic field bumps, and coil tests to determine eddy-current effects, there were no serious resonance problems during the compression cycle such as had occurred in the early Compressor 2 experiments. There was a minute loss on the n = 0.25 resonance, which could probably be eliminated with an n-corrector circuit.

The minor radius of the compressed ring was a few millimeters--similar to that in the Compressor II experiments. With coil sets 1, 2, and 3 energized the ring lasted for about 15 msec; the eventual loss was apparently due to the decay of the magnetic field.

To test resonance losses during extraction, a capacitor bank was energized which increased the current in the left-hand solenoid and decreased the current in the right-hand solenoid. The unbalancing circuit is critically damped so the fields return to their usual symmetry in a few hundred μsec By this method it was possible to roll the electron ring to various distances to the right of the midplane and have it return. As the ring moved to the right of the midplane

it moved from a region with $n = 0.1$ to a region of $n = 0$ at the point of spillout. By increasing the unbalance current it was possible to expose the ring to lower values of n and then bring it back to the midplane to note the change. (As n is brought closer to zero, the $\nu_R = 1$ and $\nu_Z = 0$ resonances are approached, with possible passage through the $\nu_R = 1$ resonance; ν_R and ν_Z are of course modified by ion loading and the presence of an image cylinder.) The ring survived this motion until the unbalance current was great enough to push it to the spillout point. The ring was then observed to strike a probe about 10 cm to the right of the spillout point. From the long spill (several μsec) it was observed that the ring did not move as an integral unit, but betatron amplitudes peeled off axially as they reached the spillout point. There was no evidence of a resonance loss unless it occurred exactly at the spillout time. Ion loading and putting an image cylinder inside the ring did not affect the loss time, giving further evidence that the loss is not caused by a resonance. However, the fact that the ring did not accelerate axially as a unit indicates that axial focusing from ion and from image charges was not large enough. Much work must be done on extraction during the next run.

In general the mechanical and electrical components of Compressor III worked very well. However, the base pressure was not so low as needed for extraction due to (a) leaks in the movable seals of the left-hand probes and (b) the fact the liquid helium finger could not be activated in time for this run.

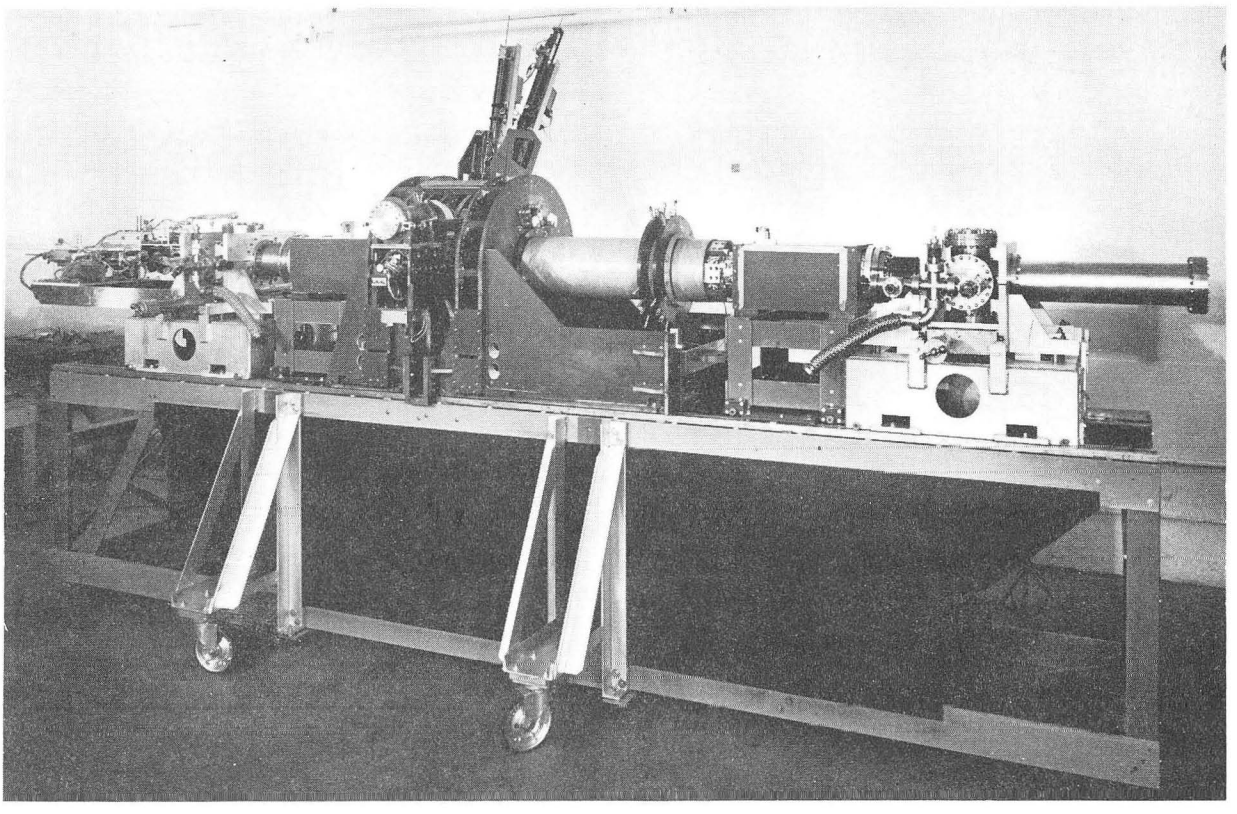

Fig. 2. Compressor III.

Compressor III--Between Runs

Several repairs and modifications were made to improve the vacuum situation. For example, the sliding seals on diagnostic probes were replaced by bellows, and the mounting of the injection snout was rebuilt. The liquid helium cryo-pumping system was finally completed, and operated satisfactorily in a test.

A major modification has been the conversion of the dielectric-type image cylinder to a metal squirrel-cage type by plating thin copper stripes down the length of the active region of the cylinder. This increases the effective image-focusing forces by about 25%. The beam scraper was modified so that a current signal as well as an x-ray signal could be obtained when the beam struck it. Two additional ion-detecting probes were added: One is a Faraday cup device that can be shadowed by two movable foils to measure ion ranges, and one of the foils is cerium to allow a search for the $Ce(^{14}N, 3\text{-}5n)^{149}Tb$ reaction. The other added ion-detection system is a reentrant tube extending from the right almost to the end of the accelerating region with a 1-mil aluminum foil window. Nuclear emulsions or electronic detectors (or both) will be used in this probe.

Electron Injector Facility

A model ferrite-loaded cavity (which simulates one accelerator section of a typical linear induction accelerator) was tested, and the results were encouraging. The model cavity has been tested to a maximum voltage of 280 kV, and has passed 2800 A of electron current at 200 kV with a 30–35-nsec pulse length. A "life test" is in progress, and more than 200 000 pulses have been accumulated.

It was decided that the 1.2-MeV initial accelerating gun potential would be supplied by stacking four or five pulsed accelerating cavities close together. Other cavities, for acceleration to 2.2 MeV, are under construction.

An experimental-theoretical program for gun design has started. Astron uses a hot cathode, but we hope to be able to use a simple field-emission cathode. Theoretical design calculations have begun: these have been directed toward understanding the sparse experimental data available, and will guide the experimental program.

The construction program for the new electron injector facility is on schedule. The bulk of the excavations for the shielded enclosure has been completed, and the caissons are being drilled. After the tunnel is completed in March, assembly of the accelerator sections inside the tunnel will begin.

PUBLICATIONS AND PAPERS

1. Andrew M. Sessler, The Acceleration of Particles by Collective Fields, UCRL-19223, June 1969.

2. Denis Keefe, ERA Development at Berkeley (UCRL-18896, Sept. 1969), presented at VII International Conference on High Energy Accelerators, Yerevan, USSR, September 1969.

3. Andrew M. Sessler, Collective–Field Acceleration (UCRL-19242, July 1969), presented at VII International Conference on High Energy Accelerators, Yerevan, USSR, September 1969.

4. L. Jackson Laslett, Electrostatic and Magnetostatic Image–Field Coefficients (UCRL-18892, May 1969), presented at VII International Conference on High Energy Accelerators, Yerevan, USSR, September 1969.

5. Jack M. Peterson, Electron Ring Accelerator for Heavy Ions, presented at Gordon Conference on Nuclear Chemistry, June 1969 (unpublished).

6. Alper Garren, Thin-Lens Optics with Space Charge (UCRL-19313, Sept. 1969), submitted for Proceedings of VII International Conference on High Energy Accelerators, Yerevan, USSR, September 1969.

BEVATRON

Edward J. Lofgren in charge

COMPUTER CONTROL

Significant improvements in the ease and flexibibility of setting up Bevatron operating modes were again achieved during this report period.

The area of major improvement was in control of the complex pulse modes of the Bevatron magnet power supply. The main magnet motor generator sets are now under the control of a computer system employing a DDP-8 digital processor and a program called "BMAG."

The demand for such a control system was the result of the successful placing into operation in the recent past of a new system of generating flattopped magnet pulses. This new system allowed a wide variety of new pulse modes--including very long flattops, mezzanines, and back porches--during the magnet pulse. Flattops, mezzanines, and backporches are zones within a magnet pulse in which the magnet current is held essentially constant. It is during these constant-current zones that particle beams are produced for the experimental program. These new and improved modes of operation now allow multiple beam operations with long beam spills at as many as three different primary beam energies during a single Bevatron pulse. Setting up these multiple modes, using the existing control system, was a complex process and somewhat time-consuming. These levels has been set up by adjusting time delay circuits triggered from fixed current reference markers. In the present complex pulsing modes, as many as eleven variables had to be adjusted to provide the desired magnet current profile.

In the BMAG program, the PDP-8 samples the Bevatron magnet field each millisecond as a function of the integral of B. When the desired value of field is reached, a control pulse is sent from the PDP-8 to the control circuits of the Bevatron magnet power supply, either switching the circuits to the desired flat portion of magnetic field or ending the flat portion, depending on the desired pulse profile. To set up a particular magnet pulsing profile the operator simply requests, via teletype input, the flat portion at the specified field level. Prior to pulsing the magnet, a profile analysis is provided by the computer to determine if the requested profile is within the operating parameters of the machine. In addition it provides a rapid method of optimizing the various operation parameters, and allows comparison between different profiles. Such an optimization is required in order to maximize lengths of flat zone to determine maximum permissible pulse rate. Optimization of these parameters is of primary concern for the present multiple beam operations.

Computer control of 18 pulsed-programmed magnets in the external proton beam transport system was discussed in the preceding physics semiannual report. During the period covered by this report, an additional 10 pulsed magnets and 12 dc magnets were placed under computer control, bringing the

total to 40 magnets. The pulsed magnets track the energy of the proton beam during the acceleration cycle, thus allowing several beam pulses of different energy to be transmitted through the EPB system during a single Bevatron pulse. In addition, a perturbation mode that allows compatible operation of both inner- and outer-radius targets in the Bevatron is now under the control of the computer system. This mode provides appropriate sudden shifts in the current levels of some EPB system magnets. The successful use of both inner- and outer-radius targetry during a beam pulse has allowed production of short spills for bubble chamber and long spills for counters and spark chambers with good efficiency. The perturbation mode has been found useful in some other areas of operation also. In particular it has been useful during occasions when we have spilled beam at more than one energy during a Bevatron pulse, and when one experiment had unusual tracking requirements in the external beam channels. In these cases the normal energy-tracking ($\int \dot{B}$) and tracking-program adjustment of the magnet current control did not have sufficient range to provide the proper current level at the next flat portion of field. The perturbation mode provides necessary correction, allowing proper current level for each beam spill zone.

RESONANT EXTRACTION

During a shutdown in July, a new thin-septum magnet (M1) was installed in the east straight section to further the studies of resonant extraction of the external proton beam. The septum of the new extraction magnet is 0.130 in. thick, compared with 0.50 in. thick for the magnet that was removed. With the new magnet, resonant extraction efficiency has been measured to be about 80%. This value agrees with calculations. A thin-septum quadrupole magnet (Q1) was also installed.

Tests of the resonant extraction system are expected to continue for the next 6 months or so. In the meanwhile, beam extraction employs the energy-loss principle but uses the new extraction magnets. Extracted-beam measurements, with the new magnets and using the energy-loss target, gave a beam spot at the machine exit port comparable to that observed with the original two-magnet system. The extraction efficiency, however, is increased from 35% to 50% of the internal beam.

SEPTUM EPB CHANNEL

The foundation was poured for a new beam backstop for the future septum-split beam from Channel I. The beam will be split at the second focus of EPB Channel I (F2). In the present installation the proton beam in Channel I passes through the F2 target region and is refocused on the F3 target. Beam sharing between the two target areas (F2 and F3) is difficult if one set of experimenters wishes to vary the intensity of the beam on their target. Also the beam spot at the F3 focus is often larger than desired after having gone through the F2 target. To eliminate this problem the F2 target area is being reworked to provide a septum-split beam, using septum bending magnets. In this manner a controllable but variable fraction of the beam may be delivered to targets at the backstop target area of the present Channel I and the new septum channel. The foundation for the new systen is finished, and the beam transport components are under fabrication. The septum system is scheduled to be installed during December 1969 and January 1970.

BEVATRON OPERATION

During the period covered by this report we provided beam for 19 primary and 6 secondary experiments. Five primary experiments were completed. We achieved a peak beam intensity of 5.2×10^{12} protons per pulse and accelerated a total of 5.2×10^{18} protons in the period from May through October 1969. During this period, we provided 218 12-hour periods of machine operation for experimental physics. We integrated a total of 340 12-hour periods of data taking and 312 periods of tuning for primary experiments. An additional 97 12-hour periods were integrated by secondary experiments. A total of 750 12-hour periods were integrated by high energy physics experiments.

The Bevatron was shut down for maintenance and modification on July 4, 1969. Operation was resumed for high energy physics on August 12, 1969. The major jobs during this shutdown were the installation of the new M1 and Q1 magnets and reworking of the west tangent tank face plate to permit repositioning of the M3 magnet. M3 is the third bending magnet in the external proton beam extraction system. This magnet was repositioned to reduce beam loss due to aperture restriction at the exit of the Bevatron.

MACHINE STUDIES

Machine studies continued this period, with the bulk of the time devoted to resonant extraction work, high beam studies, and studies of vertical beam blowup. The resonant extraction work has been mentioned above. High beam studies continue with nothing new to report. Vertical beam blowup has been observed to result in beam loss in two separate regions of the Bevatron acceleration cycle. The first region of vertical growth occurs during acceleration at about 200 to 300 msec after injection. At this time, the beam grows from about 0.4 of the starting vertical amplitude to about 0.6 of the starting amplitude. It then follows a normal damping curve to the end of the accelerating cycle. It ends up, however, with a larger amplitude than it would have had if it had continued to follow the original damping curve from injection. This growth is independent of beam intensity and appears to be affected by radial position. We are, however, unable to eliminate the growth of radial tracking. At high intensity the beam is larger vertically than at low intensity because of initial injection emittance.

The beam growth plus the larger beam size at high intensity results in a loss of beam on the resonant-extraction magnet bump coil when it is plunged into the beam aperture. The loss is from 10% to 25% of the accelerated beam. The second effect was observed several years ago, but was not studied in detail until recently. If the rf voltage is turned off during flattop and the beam allowed to coast, the beam is observed to grow in the vertical direction from about 2 in. full height to 7 or 8 in. in 400 to 800 msec. The effect is related to beam intensity, but is independent of the radial position of the beam.

Both the vertical growth problems are under study. We hope to either find and eliminate the cause of growth or to install devices that will restrict the growth.

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1. Robert W. Allison, Jr., H. A. Grunder, and Glen R. Lambertson, Handling Field Nonlinearities in the Bevatron Resonant Extraction (UCRL-19213, Aug. 1969), presented at VII International Conference on High Energy Accelerators, Yerevan, USSR, September 1969.

2. Robert W. Allison, Jr., Robert W. Brokloff, R. L. McLaughlin, Robert M. Richter, Marsh Tekwa, and John R. Woodyard, A Radiation-Resistant Chromium-Activated Aluminum Oxide Scintillator, UCRL-19270, July 1969.

3. Walter D. Hartsough and William S. Gilbert, Joint Nimrod-Bevatron Meeting, Abingdon, England, August 21-22, 1969, Bev-1045 (unpublished).

184-INCH CYCLOTRON

James T. Vale in charge

EXPERIMENTS CONCLUDED

The 184-inch cyclotron was used for research experiments approximately 96.6% of the time that the crew was on duty. No major outage was encountered.

During this period major experiments were concluded:

1. Pion production: Nagle et al., Los Alamos
2. Radiative capture of π^- in nuclei: Parsons (Crowe)
3. Muon-capture γ rays: Kaplan (Moyer-Helmholz)
4. Continued radiological treatment of patients (John Lawrence)
5. Biomedical effects of π^-, continued: Raju (Richman)

In addition,

1. Emulsion studies (Heckman)
2. Beam dynamics studies (Judd)

SETUPS

Setups for experiments include:

1. π^0 Form factor: Perez-Mendez (Moyer-Helmholz)
2. Magnetic moment of μ^- (Williams, U. of Washington; Crowe, LRL)
3. $\pi^+ + A \rightarrow 2p + A^0$: Burman (Los Alamos)
4. Relocation of setups for Kaplan and for Raju.

BEAM TRANSPORT MAGNETS

Two "C" magnets were received, to be used in experimental setups for beam transportation and beam-analyzing purposes. The interchange of such magnets between the 184-inch cyclotron and the Bevatron will continue, but the additional magnets will help to alleviate some of the complications that have arisen because of scheduling.

MESON CAVE PLATFORMS

Experimental setups are placed on steel tables to locate them at beam height. These platforms have steel legs with cross bracing to support the heavy loads placed upon them. Therefore, it has been very difficult to provide adequate shielding from the background radiation that enters the equipment from below. The simplest solution is to replace these steel tables with solid platforms made of concrete. A group of appropriate concrete blocks was delivered, and they will be installed during the next experimental setup.

MODIFICATION STUDIES

Engineering studies of the increased-intensity modification have continued. This has been on a strictly limited scale, because of budget considerations, but the engineering outlook is now very promising. Most of the major mechanical problems now appear solvable. However, it must be emphasized that only the broad general aspects have been studied, and the details have been postponed until funds become available.

NEW SECOND DEE SYSTEM

Design and model studies for the new cee electrode system have continued. The MacKenzie system[1] for high-power broadband frequency modulation has been chosen to provide 20 kV cee voltage with a frequency sweep of 0.6 MHz in the range from 20.2 to 19.0 MHz, with a power requirement of 40 kW.

A working full-scale model was constructed for two possible locations in the vacuum chamber. The location chosen provides space for possible future devices to improve the external beam intensity. Mechanical layout and design work has paralleled the rf model.

The model operates at 1 kV cee voltage, with a feedback loop to maintain constant voltage throughout the frequency range.

The power amplifier tube for the design being studied will require a minimum of additional auxiliary equipment. A resonant transformer and damping diode[2] in series with the present power supply will program the anode voltage, providing increased voltage at the beginning and end of the FM cycle, and reduced voltage at the center of the cycle. The resonant system also reduces the power dissipation, and thereby allows the use of the present power supply for the new system.

1. K. R. MacKenzie, High Power Broadband Frequency Modulation of High Q Resonators, Nuclear Instr. Methods 61, 134-140 (1968).
2. K. R. MacKenzie (University of California–Los Angeles), private communication.

Appendix

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