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PHYSICS
Semiannual Report

November 1968 through April 1969

May 1969

David L. Judd
Associate Director for Physics

LAWRENCE RADIATION LABORATORY
University of California
Berkeley, California

PHYSICS SEMIANNUAL REPORT

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Physics Research

THEORETICAL PHYSICS

Geoffrey F. Chew in charge

I. HIGH-ENERGY PHYSICS

SMALL HADRONIC PARAMETERS AND A PRINCIPLE OF COMPLEMENTARITY FOR BOOTSTRAP MODELS

Geoffrey F. Chew

The conjecture has been formulated that, although no single bootstrap model may be capable of explaining the small parameters that motivate its construction, an assortment of complementary models may collectively span the entire hadronic S matrix, with all parameters determined. The relevance of this conjecture to a combination of zero-width and multiperipheral models is being explored.

MULTIPERIPHERAL DYNAMICS

Geoffrey F. Chew and William R. Frazer*

Using the multiperipheral integral equation, we have constructed a model to elucidate the interrelation of Regge poles and cuts. In the elastic amplitude, the most plausible solution places the Pomeranchuk trajectory at a height slightly below 1: $\alpha_P(0) = 1 - a$, where $a \gtrsim 0.01$. The corresponding AFS branch point appears at $J = 1 - 2a$ and has a discontinuity corresponding roughly to the elastic part of the cross section. The extension of these ideas to nonforward and to inelastic scattering is being pursued.

MULTIPERIPHERAL DYNAMICS

Geoffrey F. Chew, Terence Rogers,† and Dale Snider

The ABFST multiperipheral equation multiple pion exchange has been reformulated in BCP variables so as to allow diagonalization, and the kernel is being computed from the best available information on elastic $\pi\pi$ scattering. The smallness of the effective multiperipheral Pomeranchuk coupling has been related to the small (~1 mb) elastic $\pi\pi$ cross section at very high energies. The kernel of the integral equation turns out to be dominated by $\pi\pi$ subenergies in the resonance region near 1 GeV, the Pomeranchuk contribution being relatively insignificant.

*University of California, San Diego.
†Postdoctoral Harkness Fellow.

MULTIPERIPHERAL REGGE-POLE EXCHANGE MODELS

Edmond L. Berger‡

Work is continuing in an effort to fit data on three- and four-body production processes using multiperipheral Regge-pole exchange diagrams. Under consideration are the reactions $pp \to pn\pi^+\pi^+\pi^-$ ($n\Delta^{++}\pi^+\pi^-$) at 28.5 GeV/c and several processes in which the A_1 effect is observed, for example, $Kp \to K(\pi\rho)p$. Both meson and baryon exchanges are employed.

MODELS FOR PHOTOPRODUCTION PROCESSES WITH EVASIVE REGGE POLES AND CUTS GENERATED BY ABSORPTION

J. D. Jackson and C. Quigg

1. π^+ photoproduction

The work on high energy photoproduction of positive pions and the information contained in finite-energy sum rules, described in the last report, has been completed, written up, and accepted for publication in Physics Letters.[1] The essential results of this work are: (a) We construct a model with evasive Regge

‡On leave from Dartmouth College, Hanover, New Hampshire.
1. J. D. Jackson and C. Quigg, Charged Pion Photoproduction and Finite Energy Sum Rules, UCRL-18764, February 1969; Phys. Letters (to be published).

poles and associated Regge cuts that fits both the high-energy differential cross sections (including the data with linearly polarized photons) and the continuous-moment finite-energy sum rules. (b) We show that the normal finite-energy sum rules, in fact, determine approximately the real parts of the photoproduction amplitudes at the upper limit of integration. (c) We develop a pseudomodel which directly relates the finite-energy sum rules to the high-energy data without the need for commitment to any particular theoretical model. Our most important conclusion is that, although finite-energy sum rules for photoproduction allow an immediate connection between the low-energy and high-energy regions, they make no distinction among a large class of models and, in particular, do not establish the existence of a pion conspiracy in photoproduction of pions.

2. Pseudomodels from FESR

As an outgrowth of the work described above, a brief investigation is being made to survey all the possibilities for pseudomodels based on FESR. One application is to the prediction of photoproduction from a polarized proton target. Other results and possible applications are still to come.

3. π^0 photoproduction

A model with ω exchange plus absorptive corrections fails to fit the energy dependence of the high-energy differential-cross-section data. The additional exchange of a lower (ω') trajectory with quantum numbers of the ω is suggested by finite energy sum rules. A ρ-π cut could be added, rather than the ω'. This possibility, as well as others, is under investigation.

4. K^+ photoproduction

The differential cross sections for $\gamma p \to K^+\Lambda^0$ and $\gamma p \to K^+\Sigma^0$ can be satisfactorily described by a model with K and $K^*(1420)$ exchange, plus absorptive corrections, in analogy with our model with π and A_2 exchange, plus absorption for π^+ photoproduction. The qualitative difference between the K^+ and π^+ reactions is due to the large K-π mass difference.

5. π^+/π^- ratio in $\gamma N \to \pi^\pm N'$

We are attempting to obtain a description of both π^+ and π^- photoproduction, through the addition of ρ exchange to the model we described in Ref. 1 of this article.

PROGRAMS FOR ABSORPTIVE MODEL CALCULATIONS

J. D. Jackson and C. Quigg

The absorptive model of peripheral processes, in the version developed independently by Donohue[1] and Keyser,[2] employing exact partial-wave summations instead of the impact-parameter representation,[3,4] has been modified to work on the LRL computer (CDC 6600). This task was undertaken as a service to the experimentalists who wish to compare their quasi-two-body production data with the predictions of the absorptive model. The original programs are those of Donohue from the University of Illinois. The present versions have been checked by comparison of a mumber of typical calculations with output from Urbana.

The reactions presently available are PB(P, V, B, D)VB, PB(P, V)VD, and PB(V)PD, where P is a pseudoscalar meson, B is a spin-$1/2^+$ baryon, V is a vector meson, D is a spin-$3/2^+$ baryon, and the exchanged particles are given in the parentheses. Processes involving particles of different parities can also

1. J. T. Donohue, Ph.D. Thesis, Department of Physics, University of Illinois, 1966 (unpublished); Phys. Rev. 163, 1549 (1967).
2. R. Keyser, unpublished CERN reports and H. Högaasen, J. Högaasen, R. Keyser, and B. E. Y. Svensson, Nuovo Cimento 42, 323 (1966).
3. K. Gottfried and J. D. Jackson, Nuovo Cimento 33, 735 (1964).
4. J. D. Jackson, J. T. Donohue, K. Gottfried, R. Keyser, and B. E. Y. Svensson, Phys. Rev. 139, B428 (1965).

be handled. The input information consists of masses, coupling constants (and ratios of coupling constants for mixtures of exchanges), the incident momentum, and absorption parameters. The output consists of the differential cross section ($d\sigma/d\Omega$) and spin density matrix elements for the decaying resonances (usually referred to the t-channel axes) as functions of center-of-mass $\cos\theta$ and momentum transfer Δ^2. The full range of $\cos\theta$ is covered, since the amplitudes are expressed in the Jacob-Wick helicity formalism using Wigner d functions for the partial waves.

THE STATIC MODEL AND THE VENEZIANO REPRESENTATION

Peter D. Ting

The Veneziano representation of the scattering amplitude is under investigation to see whether the old bootstrap model for rising trajectories, such as that proposed by Carruthers, can be explained within the language of the Veneziano model. In particular, we would like to investigate whether the Veneziano model, where the unitarity is obviously absent, can describe those resonances like N or Δ, which have been qualitatively described by the static model, where we know the threshold effect is very important.

THE 3-TO-3 AMPLITUDE AND THE TRIPLE-REGGE VERTEX

Michael N. Misheloff

Using group theoretical variables, we develop a Reggeized model for the 3-to-3 amplitude. The triple-Regge vertex is defined by the asymptotic form of the amplitude. We show that the Veneziano model has the asymptotic form predicted by our model.

DIRAC MATRICES FOR ANY SPIN AND SPIN-MATRIX POLYNOMIALS AND THE VENEZIANO FORMULA

Terence J. Nelson*

For each spin s, one can construct a completely symmetric Lorentz tensor $S^\dagger_{\mu_1\cdots\mu_{2s}}$ from the spin matrices s_i. The combinations

$$\gamma_{\mu_1\cdots\mu_{2s}} = \begin{pmatrix} 0 & -S^\dagger_{\mu_1\cdots\mu_{2s}} \\ -S_{\mu_1\cdots\mu_{2s}} & 0 \end{pmatrix}$$

are called the Dirac matrices for a spin s. Nelson and Good[1] have found a recursion formula which relates $S^\dagger_{\mu_1\cdots\mu_{2s}}$ with N+1 spatial indices to its values with N and N-1 spatial indices. If we define $z = \vec{s}\cdots\hat{\vec{p}}$ and $S^\dagger(N) = \hat{p}_{i_1}\cdots\hat{p}_{i_N}\, S^\dagger_{4\cdots 4 i_1\cdots i_N}$, where $\hat{\vec{p}}$ is an arbitrary unit vector, the recursion formula is

$$(2s-n)\, S^\dagger(N+1) = i2z\, S^\dagger(N) + N S^\dagger(N-1).$$

This recursion has been found to have the solution

$$S^\dagger(N) = (-i)^{2s}\, \frac{\Gamma(N+1)\Gamma(2s-N+1)}{\Gamma(2s+1)\Gamma(s-\frac{N}{2}+\frac{1}{2})} \times \sum_{j=0,\frac{1}{2}}^{N/2} \frac{(i2)^{2j}\Gamma(s-j+\frac{1}{2})\,\Gamma(z+j+\frac{1}{2})}{\Gamma(2j+1)\Gamma(\frac{N}{2}-j+1)\Gamma(z-j+\frac{1}{2})},$$

where the sum begins with 0 if N is even, and 1/2 if it is odd. It is easy to find $S^\dagger_{4\cdots 4 i_1\cdots i_N}$ from $S^\dagger(N)$ owing to the complete symmetry on the Lorentz tensor indices. Contraction N times with the unit vector $\hat{\vec{p}}$ only serves to bypass complicated work with commutators and

*AEC Postdoctoral Fellow.

1. T. J. Nelson and R. H. Good, Jr., Description of Massless Particles, to be published in Phys. Rev.

does not affect the final answer.

The ratio $\Gamma(z+j+1/2)/\Gamma(z-j+1/2)$ is a polynomial in z of degree 2j and has been called a spin-matrix polynomial by Weber and Williams,[1] who have investigated expansion in terms of them to some extent. It is interesting to see what other uses one might have for these polynomials. For example, one might consider expanding a scattering amplitude in them. If we take

$$A(s,z) = \sum_{n=0}^{\infty} \frac{c_n(s)}{n!} \frac{\Gamma(z+\frac{n}{2}+\frac{1}{2})}{\Gamma(z-\frac{n}{2}+\frac{1}{2})},$$

where z is now the scattering angle $\cos\theta$, then we have

$$c_n(s) = \frac{1}{2}\{\nabla^n[A(s,z) + (-)^n A(s,-z)]\}_{z=(n-1)/2},$$

where ∇ is the difference operator $\nabla g(z) = g(z) - g(z-1)$. One can go on to consider the Sommerfeld-Watson transform, and since

$$\Gamma(-z+\frac{n}{2}+\frac{1}{2})/\Gamma(-z-\frac{n}{2}+\frac{1}{2}) = (-)^n \Gamma(z+\frac{n}{2}+\frac{1}{2})/\Gamma(z-\frac{n}{2}+\frac{1}{2}),$$

this is as easy as with the Legendre series. By using $2bk_ik_fz$ in place of z, where b is the slope of the ρ trajectory, it has been shown that one is led to the Veneziano formula[2] for the process $\pi\pi \to \pi\omega$ in a very natural way.

The analytic properties of an expansion in spin-matrix polynomials remains to be explored in detail. Also a closed-form expansion of a spin-matrix polynomial in terms of Legendre polynomials is lacking. These problems will be investigated in future work.

APPLICATION OF THE VENEZIANO FORMULA IN THE AFS MULTIPERIPHERAL MODEL

Don M. Tow

Work is in progress to use the four-particle Veneziano formula for the π-π amplitude in the AFS multiperipheral model. The goal is to calculate the multiplicities, inelasticity, and the transverse momentum of the secondary particles. This calculation will be an improvement over AFS's calculation, because the unknown coefficient and constants in AFS's calculation can now be explicitly determined.

1. T. A. Weber and S. A. Williams, J. Math. Phys. 6, 1980 (1965).
2. G. Veneziano, Nuovo Cimento 57A, 190 (1968).

MESON-BARYON SCATTERING AND THE VENEZIANO MODEL

Edmond L. Berger* and Geoffrey C. Fox

We have examined in some detail the application of the Veneziano beta-function representation to the scattering of pseudoscalar mesons from spin -1/2 baryons. Our purpose was to learn whether specialization to the Veneziano model leads to increased understanding of these processes. We sought to properly treat such properties as positivity, parity doubling, SU(3) symmetry, PCAC requirements, and exchange degeneracy. Several general features of the model are helpful in gaining a qualitatively unified picture of meson-baryon scattering. However, on the quantitative side, we conclude that the model does not lead to a new, compelling parameterization of existing data, either for baryon resonance widths or for [forward and (or) backward] differential cross sections at high energy. The number of beta-function terms required to encompass present knowledge is very large; nor is there any predictive power remaining. A paper is in preparation.

MACROCAUSALITY AND DISCONTINUITY FORMULAS

Henry P. Stapp

The correspondence of quantum theory to classical theory, in appropriate limits, is assured for ordinary quantum theory by the Schroedinger equation. In S-matrix theory the correspondence to classical theory can be formulated as a macrocausality condition. This condition has been shown to be equivalent to

*On leave from Dartmouth College, Hanover, New Hampshire.

the physical-region analyticity properties exhibited by perturbation theory. Thus the basic physical-region analyticity properties of the S matrix can be understood without appealing to perturbation theory. From these analyticity properties, plus some reasonable technical assumptions, one can derive also the discontinuity across each physical-region singularity surface. This gives concrete meaning to the idea that certain singularities of the S matrix are actually required by general physical principles. This work has now been completed and submitted for publication.

CURRENT ALGEBRA

Perry Shers

Work on the previously described calculation of corrections in the physical region to the current-algebra meson-baryon scattering theorems has continued and is now near completion.

STRONG INTERACTION SUM RULES

Perry Shers

Given the analytic properties exhibited by the Mandelstam representation, one may readily formulate a variety of different single variable-dispersion relations. If any two such representations are set equal to one another at the same point, a sum rule is obtained. We have begun an investigation of the usefulness of some of these rules.

A REGGEIZED ZERO-WIDTH MODEL FOR CURRENTS

Richard C. Brower and J. H. Weis

Work is proceeding on a zero-width parameterization for the matrix elements for photoproduction, Compton scattering, and current algebra. We are generalizing the results of previous work[1] to amplitudes with N spinless hadrons and one or two off-mass-shell "currents". We have generalized the ρ-dominance model to the N-hadron photoproduction amplitudes.

ANALYSIS OF THE SCATTERING AMPLITUDE AT t = 0 BASED ON THE 0(2, 2) AND 0(4) GROUPS

Kuo-hsiang Wang

The Clebsch-Gordan coefficients of SU(1, 1) for any combinations of the unitary irreducible representations of SU(1, 1) have been obtained. Thus the unitary irreducible representation of 0(2, 2) was obtained. In the absence of the poles in the right half a-plane and b-plane (or equivalently n-plane and m-plane), the 0(4) expansion of the scattering amplitude is continued into the 0(2, 2) expansion. If there are poles in the right-half plane, the daughter phenomena occurs. Further investigations along this line will be continued.

UNIQUENESS OF THE PARAMETERIZATION OF REGGE RESIDUES AND TRAJECTORIES FOR SMALL t

J. H. Weis

The small-t expansion of Regge residues $\beta(t)$ and trajectory functions $\alpha(t)$ for arbitrary external masses and spins is discussed. All mass configurations are treated in a uniform manner. We assume the usual analyticity properties of helicity amplitudes, the factorization of Regge residues, and the requirement of consistency with coupling to unequal-mass channels. The leading term and certain nonleading terms in the small t expansions of $\alpha(t)$ and $\beta(t)$ are shown to be uniquely determined by higher-lying trajectories in the "family". For the equal-mass residues we point out that the small-t behavior is exhibited more clearly by certain linear combinations of the residues than by the residues themselves. The relationship of various recently proposed parameterizations of $\alpha(t)$ and $\beta(t)$ to our general results is discussed. In

1. Richard C. Brower and Martin B. Halpern, Veneziano Parameterization for Non-Strong Amplitude (University of California, Berkeley, preprint), February 1969.

particular, it is shown that the parameterization given by Cosenza, Sciarrino, and Toller[1] has the most general leading t behavior permitted for residues, whereas several other proposed parameterizations do not.

SINGULARITIES AND REGGEIZED AMPLITUDES IN UNITARITY

Chih Kwan Chen

The direct-channel Reggeon is put into the amplitude in the unitarity diagrams. The purpose is to investigate the generated singularities in the analytic S matrix. This model is equivalent to using not only a stable particle, but a series of resonances on this particle's Regge trajectory as the input to the analytic S-matrix approach based on the first degree of maximum analyticity.

REGGEIZED EXTERNAL LINES AND CURRENTS

I. T. Grodsky

Continuing the investigation of a set of wave-function prescriptions for coupling linearly rising trajectories, we have found an infinite class of representations of collinear current algebras. By allowing the currents to be non-Hermitian, we are investigating the possibility that one such representation is connected with the Veneziano-Mandelstam model and, if so, how to go beyond the colinear constraint.

EVIDENCE FOR THE EXCHANGE OF THE ρ AND A_2 TRAJECTORIES IN THE REACTIONS $\pi^+p \to \pi^0\Delta^{++}$, $\pi^+p \to \eta^0\Delta^{++}$, AND $K^+p \to K^0\Delta^{++}$

Robert Mathews

The work on this subject, described in the previous semiannual report, has been completed, written up in UCRL-18611, and submitted to Nuclear Physics B for publication.

1. G. Cosenza, A. Sciarrino, and M. Toller, Nuovo Cimento 57A, 253 (1968); also CERN preprints TH906, 1968 and TH1002, 1969.

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

Robert Mathews

Work is beginning 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. We would like to relate the slope of the Dalitz plot to low-energy $\pi\pi$ scattering parameters. After we have faith in a method of calculation, we should like to modify it 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.

CRUDE DYNAMICAL ATTEMPTS IN SUGAWARA'S THEORY OF CURRENTS

Arnulf Rabl

As a first step towards solving Sugawara's theory of currents, we explore the possibility that certain spectral sums might be dominated by a single-particle state. We sandwich the equations of motion for the currents between single-particle states and evaluate the bilinear current terms by inserting a complete set of intermediate states. By approximating the intermediate states by single-particle states, we can derive nonlinear equations for the form factors. When we apply this method to the energy momentum tensor, we find lower bounds for the particle masses in terms of their form factors.

PION-HELIUM SCATTERING

J. V. Lepore and R. J. Riddell, Jr.

The Crowe group at this laboratory has recently reported measurements of $\pi^\pm$ elastic scattering from ^{4}He. This work was aimed toward finding the pion form factor by studying the difference between π^+ and π^- scattering in the energy range 140- to 180-MeV pion kinetic energy. The data were analyzed by

Mottershead on the basis of treating the nuclear scattering using the Kisslinger[1] model. The model, which takes account of the effects of the S- and P-wave pion-nucleon interaction has an "effective mass" term in the Schrödinger equation which becomes infinite. We have proposed an alternative approach using the Lippmann-Schwinger equation which incorporates correct threshold and asymptotic behavior for the scattering amplitudes and which does not lead to the aforementioned singularity. Computing has begun but detailed determination of the pion form factor has not yet been completed.

VENEZIANO PARAMETERIZATION OF NONSTRONG AMPLITUDES

Arnulf Rabl

The Veneziano parameterization of nonstrong amplitudes[2] is being used to investigate the electromagnetic mass differences.

STRONG PION-HELIUM SCATTERING WITH ELECTROMAGNETIC CORRECTIONS

Ronald A. Christensen

Electromagnetic corrections to pion-^{4}He scattering are calculated to see if they can be used to determine r_π for space-like q^2. The low-momentum t dependence of the off-shell strong amplitude used in this calculation is determined with the help of crossing symmetry, current algebra, and PCAC. The relativistic corrections are found to be just as important as those which are also included in nonrelativistic treatments. Using only the nonrelativistic terms, the large (2- to 3 fermi) values of r_π obtained recently from $\pi^\pm\alpha$ scattering are reproduced. Including the relativistic terms brings the resulting values of r_π down to the range 1.0 to 1.4 fermi. Although somewhat higher than values obtained using inelastic electron-proton scattering, the $\pi^\pm\alpha$ results cannot be said to be inconsistent with them because of the sensitivity of the analysis to details of the $\pi\alpha$ nuclear interaction, which is only roughly approximated.

1. K. M. Watson and A. L. Fetter, The Optical Model in Advances in Physics, K. A. Brueckner, Ed. (Academic Press, New York, 1965), Vol. I, pages 115, 195.
2. R. C. Brower and M. B. Halpern, Veneziano Parameterization of Non-Strong Amplitudes, University of California, Berkeley preprint, February 1969.

ANALYSIS OF PION-HELIUM SCATTERING FOR THE PION CHARGE RADIUS

C. T. Mottershead

Final checks have been carried out on the analysis by a boundary condition method of $\pi^\pm$ - ^{4}He scattering data for the pion charge radius. No way was found to avoid the conclusion that $r_\pi = 2.5 \pm 0.6$ fermi. A report on this work is being prepared for publication.

BOUND STATES AND ODD POLES IN A SEPARABLE POTENTIAL

J. Urrechaga-Altuna*

The extension to higher angular momentum states of previous work[1] is being considered. The aim is to study the nature of composite particles (bound states) when CDD poles are present in a separable-potential model. Particle operators for the composite particles and their commutation relations are to be determined. S-matrix elements for different processes can then be calculated.

*Sabbatical leave from Instituto Politecnico Nacional, Mexico 14, D. F., Mexico.
1. J. Urrechaga-Altuna and O. Rojo (to be published).

II. NUCLEAR PHYSICS

ON THE NUCLEAR STRUCTURE AND STABILITY OF HEAVY AND SUPERHEAVY NUCLEI

S. G. Nilsson,* Chin-Fu Tsang, A. Sobiczewski,† Z. Szymanski,† S. Wycech,† C. Gustafson,* I-L. Lamm,* Peter Möller,* and B. Nilsson*

A shell model and a liquid-drop model have been combined to study the nuclear structure and stability of heavy elements ($A \gtrsim 150$) and of the predicted superheavy elements ($A \sim 300$). Details of the calculations may be found in the Physics Semiannual Report of May 1968.

The main results are as follows:

(1) We have calculated the masses and deformations of all known nuclei with $A \gtrsim 150$. The results agree extremely well with experiments. The masses are generally within 1 to 2 MeV of the experimental nuclear masses, and the deformations are within 10% of the experimental values.

(2) We have also calculated the masses and deformations for the predicted superheavy nuclei ($106 < Z < 128$, $176 < N < 204$). Their stability against spontaneous fission, alpha decay, and beta decay was studied. Their possible experimental production was discussed.

(3) The calculations also indicate the possible occurrence of a metastable nuclear state which corresponds to a very prolate shape of the nucleus distinct from the ground-state shape. The trends of these so-called shape isomers as a function of neutron and proton numbers were discussed in detail. In the actinide region these shape isomers may be associated with the spontaneous-fission isomers that have been experimentally studied for some years. Limited comparisons between theory and experiment were made.

*Lund Institute of Technology, Lund, Sweden.
†Institute of Nuclear Research, Warsaw, Poland.

STABILITY OF SUPERHEAVY ELEMENTS AND THEIR POSSIBLE OCCURRENCE IN NATURE

S. G. Nilsson,* Stanley G. Thompson,† and Chin-Fu Tsang

The calculations and results are described in the last semiannual report. This work has been written up and published.‡

III. PLASMA PHYSICS

QUASILINEAR EVOLUTION OF THE TRANSVERSE INSTABILITY

Norman Albright

The transverse instability (Weibel-Kahn instability) has been investigated for the case of an infinite unmagnetized plasma with different temperatures parallel to and perpendicular to a symmetry axis. The results are contained in an LRL report[1] for the case $T_{\parallel} > T_{\perp}$. A publication version is in preparation which extends the work in the above report to include the case $T_{\parallel} < T_{\perp}$.

TRANSPORT OF ELECTROMAGENTIC WAVES IN A PLASMA

Jerry Peacher* and K. M. Watson

The derivation of a radiation transport equation for scattering of electromagnetic waves by a plasma is being studied. We are particularly concerned with the shift in frequency due to electron motion. We are led to a transport equation with a scattering kernel which depends on plasma correlation functions. Fluctuations in these lead to the frequency shift and scattering of the waves.

*Lund Institute of Technology, Lund, Sweden.
†Nuclear Chemistry Division, LRL, Berkeley.
‡S. G. Nilsson, S. G. Thompson, and C. F. Tsang, Evidence Concerning ρ Exchange in the Reactions $\pi^+ p \to \pi^0 \Delta^{++}$ and $\pi^+ p \to \omega^0 \Delta^{++}$, UCRL-18351, July 1968; Phys. Letters 28B, 458 (1969).
1. Norman Albright, Quasilinear Evolution of the Transverse Instability Driven by Temperature Anisotropy of an Unmagnetized Plasma, UCRL-18759, January 1969.
*Space Science Laboratory, University of California, Berkeley, California.

ANOMOLOUS PLASMA VISCOSITY DUE TO THE TRANSVERSE WAVE INSTABILITY

Blake R. Patterson*

Investigation of anomolous plasma viscosity due to the transverse instability has begun. A shear distribution in velocity which is locally Maxwellian evolves in a natural way to a local three temperature Maxwellian. This local velocity anisotropy is susceptible to the transverse wave instability which grows until an equilibrium is reached in which wave growth is balanced by nonlinear processes. The equilibrium distribution function gives the effective viscosity due to this particle-wave interaction.

BACKSCATTERING OF ELECTROMAGNETIC WAVES FROM AN UNDERDENSE PLASMA

Yu-Yun Kuo

Multiple scattering of electromagnetic waves from an underdense plasma is being studied. The results can be applied to the backscattering from an ionic sphere.

IV. ACCELERATOR THEORY

TRANSVERSE COHERENT INSTABILITIES IN STORAGE RINGS

Eberhard Keil† and Andrew M. Sessler

Recent observations of instabilities on the e^--e^+ storage ring ADONE in Frascati, and especially the observed dependence of the phenomena upon the clearing-separating electrodes, has stimulated a reexamination of the theory of coherent instabilities.[1]

*National Science Foundation Predoctoral Fellow.
†CERN, Geneva, Switzerland.
1. Eberhard Keil and Andrew M. Sessler, Reflections on Instabilities Stimulated by Recent Observations on ADONE, CERN International Report ISR-TH/69-13, March 20, 1969.

THE ELECTRON-RING ACCELERATOR: STATIC COMPRESSORS

L. Jackson Laslett and Andrew M. Sessler

Work on this subject has resulted in a design which appears to be technically feasible and which offers advantages over other proposed compressors.[1]

THE ELECTRON-RING ACCELERATOR: COMPRESSOR III

L. Jackson Laslett

Design studies continue, as described in the last report, involving (besides the author) most of the members of the ERA Group: experimental physicists, engineers, programmers, and graduate students.

THE ELECTRON-RING ACCELERATOR: RELATIVISTIC ELECTRON INJECTOR

Alper A. Garren

Theoretical assistance is being given to the group developing an electron injector for a Berkeley ERA project.

THE ELECTRON-RING ACCELERATOR: CAVITY RADIATION

Andrew M. Sessler

The amount of radiation loss by an electron-ring which is traversing the periodic cavity structure of an accelerating column may impose important restrictions on the design of a high-energy electron-ring accelerator.

1. L. Jackson Laslett and Andrew M. Sessler, A Method for Static-Field Compression in an Electron-Ring Accelerator, Lawrence Radiation Laboratory report UCRL-18589, February 20, 1969; to be published in Proceedings of the National Accelerator Conference, Washington, D. C., March 1969.

A comprehensive study of the problem is in progress,[1] and one particular model already has been reported.[2]

THE ELECTRON-RING ACCELERATOR: COMPRESSOR II

L. Jackson Laslett and Andrew M. Sessler

Previous design work on Compressor II appeared in a report during this period,[3] and a brief summary of the experimental results obtained in the autumn of 1968 and analysis thereof was also published.[4]

V. ATOMIC PHYSICS AND MISCELLANY

SOLUTION OF LIPPMANN-SCHWINGER INTEGRAL EQUATION

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

A computer program, written by T. R. Mongan,[5] for the solution of the Lippmann-Schwinger integral equation has been substantially modified so that the region of the singularity can be more accurately treated. The region of integration over the radial momentum is divided into two parts, one from 0 to 2k and the other from 2k to infinity ($k \propto \sqrt{E}$). The integration over the first region is carried out by means of the Gaussian integration technique using Legendre polynomials. The second region is similarly handled except that Laguerre polynomials are employed.

ZEROS OF THE LAGUERRE POLYNOMIALS

Robert J. Riddell, Jr.

A computer program for the determination of the zeros of the Laguerre polynomials has been devised. These have been calculated in order that these functions may be used in the Gaussian integration technique as applied to infinite intervals. The relevant weight functions have also been calculated. The last such work was done in 1949 for the case n = 15. The method employed accurately reproduces the results for this case. For small values of x the conventional power-series expression for the Laguerre polynomials can be used, but due to large cancellations for large x, it is necessary to use an asymptotic expression derived by Tricomi.[1] The method becomes more accurate as n is increased, so that reproduction of the case n = 15 leads one to believe that the program is working well. It will be made available to one of the program-sharing facilities.

SCATTERING OF SLOW IONS BY ATOMS

Joseph C. Y. Chen* and Kenneth M. Watson

A paper has been submitted to Physical Review.† This work is continuing with applications to electron exchange in ion-atom collisions.

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1. Andrew M. Sessler, Beam Loading in the Accelerating Column of an Electron-Ring Accelerator--A Monograph, draft manuscript, December 17, 1968.
2. Barbara S. Levine and Andrew M. Sessler, Excitation of a Closed Cylindrical Cavity by a Charged Ring Moving Along the Axis at Constant Velocity, UCRL-18595, February 10, 1969; to be published in the Proceedings of the National Accelerator Conference, Washington, D. C., March 1969.
3. R. W. Allison, Jr., R. T. Avery, W. R. Baker, W. W. Chupp, E. C. Hartwig, H. P. Hernandez, D. Keefe, G. R. Lambertson, L. J. Laslett, A. V. Luccio, W. A. Perkins, J. M. Peterson, W. W. Salsig, A. M. Sessler, and F. Voelker, The Electron-Ring Accelerator Program at LRL, UCRL-18498, October 1, 1968; to be published in Proc. USSR National Accelerator Conference 1968.
4. D. Keefe, G. R. Lambertson, L. J. Laslett, W. A. Perkins, J. M. Peterson, A. M. Sessler, R. W. Allison, Jr., W. W. Chupp, A. V. Luccio, and J. B. Recken, Phys. Rev. Letters 22, 558 (1969).
5. T. R. Mongan, Mitre Corporation, McLean, Virginia, private communication.

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1. Francesco Fricomi, Ann. Mat. Pura Appl. 28, 263 (1949).

*University of California, San Diego, La Jolla, California, Department of Physics and Institute for Pure and Applied Physical Sciences.

†J. C. Chen and K. M. Watson, Electronic Transitions in Slow Collisions of Atoms and Molecules. II. Calculation of Wave Functions and Green's Functions in the Eikonal Approximation, UCRL-18827, January 1969; submitted to Phys. Rev.

Slow collisions correspond to the near adiabatic regime. The kinetic-energy operator represents a perturbation causing transitions. Matrix elements of the kinetic energy is evaluated using eikonal wave functions.

EXCITATION OF A COMPLEX ION BY ELECTRON IMPACT

Mehdi Golshani

The cross section for the excitation of a complex ion has been calculated in the distored-wave approximation. We assume that this excitation is essentially due to the tail of the perturbing potential. In the dipole approximation, the scattering amplitude reduces to a one-dimensional integral which has to be computed numerically. This integral is independent of the characteristics of the complex ion, and so it can be applied to a large class of ions.

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4. W. Bierter and K. M. Bitar, Nuovo Cimento 60A, 330 (1969).
5. W. Bierter and H. L. Morrison, J. Low Temp. Phys. 1, 65 (1969).
6. W. Bierter and K. M. Bitar, Nuovo Cimento Letters 1, 192 (1969).
7. W. Bierter and H. L. Morrison, Microscopic Derivation of the Low-Lying Excitation Spectrum of an Interacting Bose System, UCRL-18814, March 1969; to be published in Nuovo Cimento Letters.
8. Richard C. Brower and Martin B. Halpern, Veneziano Parameterization for Non-Strong Amplitude, University of California, Berkeley preprint, February 1969.
9. Joseph C. Y. Chen and K. M. Watson, Electronic Transitions in Slow Collisions of Atoms and Molecules. II. Calculation of Wave Functions and Green's Functions in the Eikonal Approximation, UCRL-18827, January 16, 1969; submitted to Phys. Rev.
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11. Geoffrey F. Chew and Carleton DeTar, Multiperipheral Dynamics at Zero Momentum Transfer, UCRL-18616, November 1968; submitted to Phys. Rev.
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15. Joseph Coster and Henry P. Stapp, Physical Region Discontinuity Equations, UCRL-18512, October 1968; submitted to Phys. Rev.
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17. J. D. Jackson and C. Quigg, Charged Pion Photoproduction and Finite Energy Sum Rules, UCRL-18764, February 1969; to be published in Phys. Letters.

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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 Wisconsin, 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

Study of the reaction $\pi^- p \rightarrow \Sigma^- K^+$ at incident pion momentum of 1.17 GeV/c has been completed and published in Phys. Rev. 165, 1483 (1968). Study of $\pi^- p \rightarrow \Lambda K^0$ at seven beam momenta between 940 and 1170 MeV/c continues.

Leptonic Decays of Eta Mesons

We are looking for the decay modes $\eta \rightarrow e^+e^-$, $\mu^+\mu^-$, $e^+e^-e^+e^-$, $e^+e^-\mu^+\mu^-$, and $\mu^+\mu^-\mu^+\mu^-$. The etas are produced in the reaction $\pi^\pm p \rightarrow \pi^\pm p\eta$ at pion momenta 1170 and 1030 MeV/c.

Analysis of $\eta \rightarrow \pi^+\pi^-\pi^0$ and the Branching Ratio $\eta \rightarrow 3\pi^0/\pi^+\pi^-\pi^0$

We have completed an analysis of the $\eta \rightarrow \pi^+\pi^-\pi^0$ Dalitz plot, using a power series expansion. In contrast to other analyses, we find that a low branching ratio $\eta \rightarrow (3\pi^0)$ is completely consistent with the Dalitz plot if one assumes the three pions to be in only the pure T = 1 state [Phys. Rev. 167, 1339 (1968)].

Radiative Pion Production

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

Production of Eta Mesons

A detailed study of the angular distributions and absolute cross sections for etas produced via $\pi^\pm p \rightarrow \pi^\pm p$ at incident pion momenta from 900 to 1200 MeV/c has been completed. The final pion-proton system is found to have a large admixture of $N^*(1238)$. In addition there is a significant amount of I = 1/2 amplitude present.[1]

B. K63 EXPERIMENT

An exposure of the 72 inch hydrogen bubble chamber to a K^- beam having laboratory 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.

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1. R. A. Grossman, L. R. Price, and F. S. Crawford, Eta Production in the Reaction $\pi p \rightarrow \pi p\eta$ at 1050 and 1170 MeV/c, UCRL-18141 rev., June 1968; submitted to Phys. Rev.

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 decay analysis for both $\Lambda\pi$ and exotic decay modes, the multiparticle final-state production analysis and a preliminary analysis of $K^-p \to \Xi K$ will be published in Phys. Rev.[1] A detailed analysis of the ΞK reaction, including data on $K^-n \to \Xi^- K^0$ and data from other laboratories is nearing completion. A paper dealing with forward peaks in reactions requiring $|S| = 2$ or $I \geq 3/2$ in the t channel (including $K^-p \to K\Xi^*$) has been submitted to Phys. Rev. Letters.[2]

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

Stanley M. Flatte, 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. Theoretical analysis is now under way.

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

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

As part of an extensive study of the reactions $K^-p \to \Sigma^{\pm}\pi^{\mp}\pi^-$ 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. 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.[1]

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

Study of the Reaction $K^-p \to \Sigma^{\pm}\pi^{\pm}$

Philip M. Dauber and Angela Barbaro-Galtieri

An analysis of charged π production by K^- on protons from 2.1 to 2.7 GeV/c is in progress. Total and differential cross sections as well as Σ^+ polarizations have been measured and are being analyzed.

The Decay $\omega \to \pi^+\pi^-$

Stanley M. Flatté

A phenomenological analysis technique has been developed for the study of two-pion mass spectra. The technique is applied to some published data on the reaction $K^-p \to \Lambda\pi^+\pi^-$, as well as some new data; the total sample corresponds to 8000 decays of the ω into $\pi^+\pi^-\pi^0$, which is probably the largest sample in existence.[2]

The Reaction $K^-p \to K^*_{1/2}(892)\,\Delta(1238)$

Jerome H. Friedman and Ronald R. Ross

The reaction $K^-p \to K^*_{1/2}(892)\,\Delta(1238)$ has been studied at 2.1 and 2.6 GeV/c. The total cross section, differential cross section, and decay correlation parameters have been measured as a function of production angle, and the results have been compared with the

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2. P. M. Dauber, P. Hock, R. J. Manning, D. M. Siegel, M. A. Abolins, and G. A. Smith, Forward Peaks in Single-Meson-Exchange Forbidden Reactions, UCRL-18789, March 1969; submitted to Phys. Rev. Letters.

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2. Stanley M. Flatte, Study of $\omega \to \pi^+\pi^-$ in $K^-p \to \Lambda\omega$ from 1.2 to 2.7 GeV/c, UCRL-18687, January 1969; submitted to Phys. Rev.

absorptive peripheral model, the Regge pole model, and the quark model.[1]

Study of K^-p Four-Pronged Reactions

Jerome H. Friedman and Ronald R. Ross

Approximately 48 000 K^-p interactions producing four charged particles have been measured on the spiral reader. Analysis of final-state interactions is in progress. Particular attention is being paid to the reaction $K^-p \rightarrow Y_0^*(1520)\,\omega$; $Y_0^*(1520) \rightarrow K^-p$; $\omega \rightarrow \pi^+\pi^-\pi^0$, where a study of the differential cross section and joint decay angular correlations is in progress.

K^- Interactions in Deuterium

Angela Barbaro-Galtieri, Maxine Matison, and Alan Rittenberg

The deuterium film of path length 5 events/ub, equally divided between 2.11 and 2.65 GeV/c, has been scanned. Measurements have been made on Franckensteins and the spiral reader of 50 000 events of the following topologies: three or four prongs with or without a secondary decay, and one to four prongs with a vee. All ambiguities have been looked at on the scanning table, and the data are now in the final analysis stage.

Search for T = 3/2 resonances in the $K\pi$ System

Here, too, the evidence for a higher isospin state is negative. The other mass combinations in three-and four-prong states are now being searched for production of other resonances.

The Reaction $K^-p \rightarrow K^*_{1/2}(892)\,N^*_{3/2}(1238)$

Jerome H. Friedman and Ronald R. Ross

The reaction $K^-p \rightarrow K^*_{1/2}(892)N^*_{3/2}(1238)$ has been studied at 2.1 and 2.6 GeV/c. The total cross section, differential cross section, and decay correlation parameters have been measured as a function of production angle, and the results have been compared with the absorptive peripheral model, the Regge-pole model, and the quark model.[1]

1. J. H. Friedman and R. R. Ross, Phys. Rev. Letters 22, 152 (1969).

Study of K^-p Four-Pronged Reactions

Jerome H. Friedman, Ronald R. Ross

Approximately 48 000 K^-p interactions producing four charged particles have been measured on the spiral reader. These events have been analyzed with the aid of the Group-A data-reduction computer codes. Anlaysis of final-state interactions in the reactions $K^-p \rightarrow K^-p\pi^+\pi^-$ and $K^-p \rightarrow K^-p\pi^+\pi^-\pi^0$ are in progress. The feasibility of studying $K^-\pi^-$ scattering using the first-mentioned reaction is being investigated.

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. Roughly 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 percent of the film has been scanned twice, and about 6 percent of the film has been scanned three times. A total of 435 000 measurements has been made. All events have been processed on the CDC 6600 computer, and the analysis is in progress.

Direct Evidence for the Multiplet Assignments $\Lambda(1520)$ and $\Lambda(1405)$

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

A measurement has been made of the relative signs of the resonant $K^-p \rightarrow \Sigma\pi$ reaction

1. J. H. Friedman and R. R. Ross, Phys. Rev. Letters 22, 152 (1969).

amplitudes coming from partial waves corresponding to $\Sigma(1385)$, $\Lambda(1405)$, and $\Lambda(1520)$. From this it is shown that $\Lambda(1405)$ and $\Lambda(1520)$ are to be described as predominantly SU(3) singlets. This work has been published in Phys. Rev. Letters.[1]

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_+^+, and β_-^-, we have scanned and measured roughly 70 percent of our film for the reactions $\Sigma^\pm \to \pi^\pm n$, followed by $np \to np$. 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 are submitting the results to the Physical Review.

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_-^-.

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

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

We are analyzing a sample of 140 000 events of the type $K^-p \to \Sigma^\pm\pi^\mp$. We have determined the angular distributions for these reactions and are working on a partial-wave analysis.

Σ^- Capture in Hydrogen

When Σ^- comes to rest in hydrogen, the reaction $\Sigma^-p \to \Sigma^0 n$ or $\Sigma^-p \to \Lambda n$ occurs. One can investigate the form of the matrix element for $\Sigma^-p \to \Lambda n$ by investigating the correlation of the Λ polarization with respect to the Σ^- polarization. About 700 such events have been analyzed; another 500 are expected.

Σ^- and Σ^+ Interactions

We can study Σ^-p and Σ^+p interactions from 100 to 600 MeV/c incident Σ momentum. Due to the scarcity of events, probably only cross sections can be obtained. About 150 $\Sigma^-p \to \Sigma^0 n$ and $\Sigma^-p \to \Lambda n$ have been analyzed; another 75 are expected. $\Sigma^-p \to \Sigma^-p$ and $\Sigma^+p \to \Sigma^+p$ have not yet been measured; about 100 of each are present in our film.

1. R. D. Tripp, R. O. Bangerter, A. Barbaro-Galtieri, and T. S. Mast, Phys. Rev. Letters 21, 1721 (1968).

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

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

After measurement of most of the events of the type $K^-p \to \Lambda\pi^+\pi^-$ 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. 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. We have also isolated a signal of some 260 events corresponding to the decay $Y_0^*(1520) \to \Lambda\gamma$. This is the first reported evidence for the electromagnetic decay of a hyperon resonance. The angular distribution and polarization of the Λ are consistent with a pure electric-dipole transition. The cross section yields a partial width of 0.15 ± 0.03 MeV for the decay. A letter on this subject has recently been submitted to Phys. Rev. Letters.[1]

1. T. S. Mast, M. Alston-Garnjost, R. O. Bangerter, A. Barbaro-Galtieri, L. K. Gershwin, F. T. Solmitz, and R. D. Tripp, Electromagnetic Decay of the $Y_0^*(1520)$ UCRL-18328 Rev., August 1968; Phys. Rev. Letters 21, 1715 (1968).

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

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

The momentum range of the incident K^- has been extended up to 430 MeV/c. About 31000 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. An accurate measurement of the cross section and angular distributions will be available soon. The elastic events are necessary in order to compute the amplitudes of the two isospin channels. Altogether, 52000 events of this type have been measured and processed. Their analysis is progressing.

$\Sigma^+ \to p\gamma$

Lawrence K. Gershwin

About 60 events of the type $\Sigma^+ \to p\gamma$ have been found. The decay asymmetry is measured and found to be -1.1 ± 0.50, whereas U-spin invariance would require that the asymmetry parameter be zero. The branching ratio $\Sigma^+ \to p\gamma/\Sigma^+ \to p\pi^0$ is also being studied.

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

Terry S. Mast and Lawrence K. Gershwin

A detailed analysis of 51000 $K^- \to \pi^-\pi^-\pi^+$ 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, $= 0.247 \pm 0.009$. Comparison of this slope with that derived from a world compilation of 28000 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 submitted to the Physical Review.[1]

Rare K^- Decays

Lawrence K. Gershwin

We are also analyzing a sample of $K^- \to \pi^-\pi^-\pi^+\gamma$ decays from which we will obtain a decay spectrum and a branching ratio. In addition, a search is being made for examples of decays of the type $K^- \to \pi^+ e^- e^-$ and $K^- \to \pi^-\pi^- e^+ \gamma$.

D. π66 EXPERIMENT

Between February and August 1966, 665000 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.

$\pi^+ d$ Interactions from 2.8 to 4.2 GeV/c

Maris A. Abolins,* Orin I. Dahl, and Paul Hoch

We have measured and processed over 21000 events in which a π^+ meson of momentum 2.8 to 4.2 GeV/c produced, in a collision

1. T. S. Mast, L. K. Gershwin, M. Alston-Garnjost, R. O. Bangerter, A. Barbaro-Galtieri, J. J. Murray, F. T. Solmitz, and R. D. Tripp, 51000 τ^- Decays, UCRL-18760, January 1969.

*Michigan State University, East Lansing.

with a deuteron, a final state where a Λ or K^0 is seen to decay. Where possible, pulse-height information from the spiral reader measuring machine was used to choose between various kinematically acceptable hypotheses; events that remain ambiguous have been examined individually by physicists and trained scanners. We are completing this examination and are studying closely and remeasuring those events which have not passed successfully through the kinematic analysis programs. Procedures and programs are being refined for extracting useful results from the final states where remaining ambiguities are significant. We have made an intensive study of the production angular distribution of the $J_1^*(1385)$ hyperon and have observed a forward peaking which cannot be explained by the usual one-meson-exchange model using known mesons. Although its interpretation is not clear, this effect (with fairly good statistics) has not been reported before. A paper has been published in Phys. Rev. Letters.[1] Our data, with similar results from other, related reactions, will also be submitted to Phys. Rev. Letters. In addition, we are making a survey of the production cross sections (and, where feasible, angular distributions and decay correlations) for various meson and baryon resonances throughout this energy range.

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

Maris A. Abolins,* Orin I. Dahl, Jerry Danburg, Donald Davies, and Robert Rader

A total of 128 000 four-prong events were found, and these were measured on the spiral reader, yielding 102 000 passing events. Of these 21 000 fit the final state $\pi^+d \rightarrow pp\,\pi^+\pi^-\pi^0$. This final state has been examined for the reactions $\pi^+n \rightarrow p\eta$; $\eta \rightarrow \pi^+\pi^-\pi^0$ and $\pi^+n \rightarrow p\omega$; $\omega \rightarrow \pi^+\pi^-\pi^0$. An analysis of the ω production and decay characteristics has been performed using the model of ρ exchange with absorptive corrections. This work was reported at the APS Meeting in New York City in February 1969.

We have also measured 10 000 strange-particle events from this same exposure, giving information on 20 different final states. Comparison of this data with theoretical predictions was also reported at New York.

In addition 4000 five- and six-prong events were found in this exposure; these have been measured and fitted, yielding mainly (a) $pp\,\pi^+\pi^+\pi^-\pi^-$, (b) $pp\,\pi^+\pi^+\pi^-\pi^-$ (π^0 or γ), and (c) $pn\,\pi^+\pi^+\pi^+\pi^-\pi^-$ final states. Production of η' is observed in (b).

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 4000 tracks has been completed for use in the study of the center-of-mass momentum distributions.

We are using statistical-model parameterizations to fit the longitudinal and transverse center-of-mass momenta distributions. We find that we are able to separate the π^+ from the proton distributions without kinematic fitting of the events. We are studying the dependence of the parameters on the incident-beam energy and the multiplicity of the interaction. Preliminary results of this work were

1. M. A. Abolins, O. I. Dahl, and P. Hoch, Phys. Rev. Letters 22, 427 (1969).

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† Space Sciences Laboratory, Berkeley, California.

presented at a meeting of the American Physical Society in December 1968.[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.

F. P67 EXPERIMENT

Antiproton Interactions in Hydrogen and Deuterium

Maris A. Abolins,* Alan Rittenberg, and Gerald Smith*

An experiment involving antiproton interactions in hydrogen and deuterium from 1.5 to 2.0 GeV/c is currently under way. This is a collaboration with the Michigan State group involving the Brookhaven National Laboratory's 31-inch hydrogen bubble chamber and the Argonne National Laboratory's 30-inch deuterium bubble chamber. Approximately 50 000 measurements of interactions in hydrogen have been completed at Michigan State University, and an analysis of elastic scattering and isobar production has been completed. At LRL, approximately 210 000 interactions in deuterium have been measured, and analysis of the data is currently under way. The purpose of the experiment is to study resonance production in the direct channel as reported by previous experiments measuring total cross sections in hydrogen and deuterium. Resonances produced in the final state will also be examined.

1. D. B. Smith, J. A. Anderson, J. Kirz, and R. Sprafka, Multiparticle Final States Produced in Proton-Proton Interactions Between 13 and 28.5 GeV/c, UCRL-18523 Abstract, October 1968; presented at APS meeting, San Diego, December 18-20, 1968.

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G. ANTIPROTON INTERACTIONS IN DEUTERIUM: ITALIAN COLLABORATION

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

An experiment is being done by a collaboration of three Italian laboratories (Padua, Pisa, Turin) with LRL physicists. The film has been taken in the 81-cm hydrogen bubble chamber at CERN and is now being measured on spiral reader I. The $\bar{p}$ momenta are 0.9 and 1.2 GeV/c.

H. D66 EXPERIMENT

Philippe Eberhard, Gerald R. Lynch, and Morris Pripstein

During 1966 an exposure of approximately 210 000 pictures was taken in the 72-inch deuterium-filled bubble chamber with an incident deuteron beam at 4.4 GeV/c, for purposes of studying deuteron-deuteron interactions. All the film has essentially been scanned and measured. The events were measured on the spiral reader, and the measurement data were then processed on the CDC 6600 using the Group A programs (TVGP, SQUAW, ARROW). We are in the midst of an analysis of the results of these measurements. The analysis is complicated by the presence of biases which are inherent in a study of dd interactions in a bubble chamber. We have made substantial progress in analyzing these unique biases and isolating their effects.

I. P65 EXPERIMENT

The 72-inch hydrogen bubble chamber was exposed to protons at 5.5 and 6.6 GeV/c in 1965.

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

Eugene Gellert and Gerald A. Smith*

We have measured and fitted 32 000 two-prong and 61 000 four-prong events at a momentum of 6.6 GeV/c. Although this is only a fraction of the events on our film, no more measurements are planned at this time. We have studied the reactions $pp \rightarrow \Delta^{++} p\pi^-$, $pp \rightarrow \Delta^{++} p\pi^-\pi^0$, and $pp \rightarrow \Delta^{++} n\pi^+\pi^-$ in order to make an experimental comparison between on- and off-mass-shell inelasticities in $\pi^- p$ scattering.[1] We have also performed a double-Regge-pole analysis of $pp \rightarrow \Delta^{++} p\pi^-$ at 6.6 GeV/c.[2] We have been studying various single-particle momentum distributions in order to determine the validity of several theories of nuclear structure (e.g., Krisch's multishell model, the nonrelativistic statistical mode, etc.). We plan to write a paper on this subject entitled pp Inelastic Scattering and the Structure of the Nucleon, which will be submitted to Phys. Rev. Letters.

Analysis is underway, of the events $pp \rightarrow pp\omega$, which constitute 7.0 ± 6 percent of the sample $pp \rightarrow pp\pi^+\pi^-\pi^0$, in order to determine the appropriate exchange mechanism for these events. A double-Regge-pole analysis is planned. An analysis of the two-prong events, as well as a corollary analysis of pd interactions at the same momentum is currently underway.

Strange-Particle Interactions in pp Collisions at 5.5 and 6.6 GeV/c

A. Barry Wicklund and Gerald A. Smith*

In collaboration with University of California, Los Angeles, we have analyzed approximately 15 000 strange-particle-production events in pp collisions at 5.5 and 6.6 GeV/c. A comprehensive article for Physical Review is currently in preparation. Although the one-pion exchange model gives a good description of the data, asymmetries in the Treiman-Yang distributions and other anomalies are being investigated in terms of one-kaon exchange, absorption, and final-state interactions.

*Michigan State University, East Lansing.

1. E. Gellert and G. A. Smith, Phys. Rev. Letters 21, 1548 (1968).
2. E. Gellert and G. A. Smith, Phys. Rev. Letters 20, 964 (1968).

J. LRL-SLAC EXPERIMENT ON $\pi^- p$ INELASTIC REACTIONS

Bernard Deler, LeRoy R. Price
Arthur H. Rosenfeld, Paul Söding,†
David Herndon, 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.

As of February 1969, we have measured a total of about 300 000 two-prong events. They 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 also worked on preparing two types of analysis programs for the events. One program is a modified version of the program that is being used by Saclay, and the other is a maximum-likelihood fitting program. The Saclay program is now running, and the maximum-likelihood program should be running by late spring.

Once these programs work we should be able to establish the inelastic branching ratio of the dozen N and Δ resonances with mass below 2000 MeV. It is a remarkable fact that almost no information is available on the $\Delta\pi$ branching ratio of any of these resonances.

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K. K82 EXPERIMENT

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

A total of 600 000 pictures with 12-GeV/c K^+ incident on hydrogen in the 82-inch bubble chamber have been taken between March and October 1968. Scanning has been completed on more than 90 percent of the film, and over 200 000 events have been measured on the spiral reader. Analysis of the four-prong and vee-two-prong events is under way.

L. π82 EXPERIMENT

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

Five-hundred thousand pictures with 7-GeV/c π^+ in the 82-inch bubble chamber have been taken between January and April 1969. Studies on this film will include analysis of the A_2 splitting including $p\pi$, $K\bar{K}$, and $\eta\pi$ decay modes; the $f_0 \rightarrow K\bar{K}$ branching ratio; and the $\pi\pi \rightarrow \pi\omega$ amplitude.

M. BACKSCATTERED LASER BEAM AT SLAC

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 percent 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 percent of the photons) is 3 percent at 800 MeV, 7 percent at 3 GeV, and 10 percent at 5 and 6.5 GeV. Future modifications may extend the beam energy to 10 GeV (frequency-doubled ruby) or increase the intensity for counter experiments.

PHOTOPRODUCTION EXPERIMENTS

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

The LRL-SLAC-Tufts-U. C. B. collaboration has taken 325 000 pictures in the SLAC 82-inch bubble chamber with the back-scattered laser beam. The exposure were:

Hydrogen: 5 GeV - 160 000 pictures (50 events/μb)
3 GeV - 115 000 pictures (35 events/μb)

Deuterium: 0.8, 3, 5, 6.5 GeV - 50 000 pictures.

The scanning and preliminary analysis of the hydrogen film is about two-thirds complete. Total cross sections and preliminary data on vector-meson photoproduction have already been reported.[2] The polarization of the beam allows us to separate Pomeranchon exchange (via the vector dominance model) from other particle exchanges.

Total cross sections in deuterium will be determined at 0.8, 3, 5, and 6.5 GeV. In May 1969, 450 000 more pictures will be taken in hydrogen at 3 and 5 GeV, allowing a detailed study of many photoproduction reactions and a test of the vector-dominance model.

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

‡Visiting from Libhe, Brussels, Belgium.
2. Ballam et al., Bull. Am. Phys. Soc. (II) 14, 517 and 541 (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

We have recently 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 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. A preliminary report on this experiment is being presented at the June 1969 Lund International Conference on Elementary Particles.

Search for the Decay, $N^*(1688) \rightarrow n\eta$

We have just 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 1688 MeV and with spin-parity quantum numbers of $5/2^+$ and $5/2^-$, respectively. For this purpose, we have measured the differential cross section for the reaction $\pi^- p \rightarrow n\eta$ at six different π^- beam laboratory momenta: 880, 930, 980, 1080, and 1130 MeV/c. About 500 000 pictures have been taken, which contain about 1000 events of the final state $n\eta$, $\eta \rightarrow \gamma\gamma$ at each of these momenta. A partial-wave analysis of these angular distributions will determine the magnitude of the $n\eta$ contribution to these spin-5/2 resonances.

The spark-chamber pictures are presently being scanned and measured using the SASS device, and a preliminary report on this experiment is also being presented at the June 1969 Lund International Conference on Elementary Particles.

Neutral Diboson Experiment

With the same personnel and much of the same equipment as in the preceding spark-chamber experiments, we are also preparing for 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 is to analyze the $\pi^0\pi^0$ system in a search for scalar mesons and to measure the π-π phase shifts.

The beam for this experiment is presently in the set-up stage, and we expect to collect about 40 000 events from the above reaction.

B. DEUTERON MISSING-MASS EXPERIMENT

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

An experiment to measure the momentum spectrum of deuterons produced at 3.85, 4.6, and 6.25 GeV/c incident momenta was completed in September. The purpose of the experiment is to study the recoil charged boson mass spectrum in the region from the pion to the A_2 meson. The deuterons are produced at 180 deg in the c.m. system, and the corresponding range of laboratory momenta permitted an accurate identification of deuterons by means of a Cerenkov counter and time-of-flight and pulse-height measurements. Momentum was measured with six spark chambers employing magnetostrictive readout; the data, together with the monitor counters and a digital voltmeter recording magnet currents, was interfaced to a PDP-5 computer. Approximately two million events were taped in five Bevatron periods and 95 percent of these were momentum-analyzable. Target-empty rates were typically 30 percent of the target-full rates. Although small inconsistencies due to systemic errors are still being studied, we have measured pion and rho-meson production cross sections and can place an upper limit (0.03 μb/sr) on the possible production cross section of the "δ(963)." Our momentum resolution is better than 1 percent and the statistical significance of our measurements of boson production cross sections is of the order of 2 percent. UCRL-18241[1] describes the electronics system, and UCRL-18317[2] describes a new mathematical technique for magnetic spectrometer analysis (to be published). An article describing experimental results has been submitted for publication.

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†Space Sciences Laboratory, University of California, Berkeley.

1. R. M. Graven, F. D. Neu, H. H. Stellrecht, M. A. Torrano, M. A. Abolins, R. L. McCarthy, G. A. Smith, L. H. Smith, and A. B. Wicklund, On-Line Wire Spark Chamber System Used as a Mass Spectrometer, UCRL-18241, May 1968; submitted to Rev. Sci. Instr.
2. Arthur B. Wicklund, Rapid Spectrometer Analysis, UCRL-18317, July 1968.

III. EXPERIMENTATION USING COSMIC RAYS

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

Luis W. Alvarez, Jared A. Anderson,‡ Andrew H. Buffington,‡ Philip M. Dauber, Lester J. Lloyd, 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 benefitting 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-ft-diam pressurized sphere. With a total gondola weight of approximately 2600 lb, we expect to fly at an altitude of 120 000 feet for 10 to 20 hours, using a 20

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million cubic foot single-cell polyethylene balloon.

The first experiment will be the 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, wave-shifted Cerenkov counters, and plastic scintillators. This detector configuration (denoted as SSCM-1), with very minor or no modifications, is also suitable for several other experiments that are 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 is well along in the assembly stage. The superconducting magnet has been tested extensively in a test dewar and is presently being installed in the flight dewar. The spark chambers have been built and are being tested. Considerable work has been done on the development of the high-Z cesium iodide and wave-shifted Cerenkov counters, and these studies are being continued using a test beam at the Bevatron.

The planned launch date for the first flight is in September 1969 from Chico, California.

In addition, some time has been spent in the planning and design of the SSCM-2 gondola configuration which will be used in the measurement of the electron and positron spectra. This design would use the same basic SSCM momentum-analysis system, plus the addition of a large-volume gas Cerenkov counter and an electron-shower detector.

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, as well as a considerably larger instrument for ultimate inclusion in a manned space station.

Emulsion-Spectrograph Program

Luis W. Alvarez, Andrew H. Buffington,* Philip M. Dauber, Jerome H. Friedman, Margaret Alston-Garnjost, Lawrence H. Smith,* Frank T, Solmitz, M. Lynn Stevenson, and Michael A. Wahlig

A program is being 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 (including the CERN storage rings), in ground-based cosmic-ray experiments, and in balloon- or satellite-borne cosmic-ray experiments are envisaged. Concepts and hardware developed for the HAPPE (High Altitude Particle Physics Experiment) project will be adapted for the demonstration of the technique on a large scale, using muons. The existing, completed hardware includes the HAPPE superconducting magnet and high-resolution spark chambers. A gas Cerenkov threshold counter, an emulsion-plate scanning and measuring stage, and a support structure for the emulsions are being completed. Accurate measurement and alignment techniques are being developed. Extensive computer analysis will be necessary for calibration.

B. LRL-SLAC COSMIC-RAY EXPERIMENT

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

An optical-spark-chamber, scintillator-hodoscope array has been set up at SLAC for the measurement of muon fluxes for energies between 10 and 2000 GeV and zenith angles between 50 and 90 deg. The total geometry

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factor of the system is about 100 cm^2-sr. Data will be taken for approximately three months, starting in May 1969.

IV. MONOPOLE DETECTOR

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

A monopole detection system consisting of a superconducting coil, superconducting switch and associated electronics was constructed during this period. The system was tested and a small experiment was performed on terrestrial materials. The test would have detected a monopole as small as 1/3 of the minimum size monopole predicted by the Dirac Theory. The detection system has been disassembled and moved to the Lunar Receiving Laboratory in Houston, Texas. It is being prepared for a rehearsal of the monopole search experiment to be performed on Lunar material returned by the Apollo XI flight.

V. FLUX AMPLIFIER

Philippe Eberhard and Ronald R. Ross

A μ-metal shield has been constructed for use with the first model of the flux amplifier. Testing of the amplifier has been postponed in favor of work on the monopole detector being installed in the Lunar Receiving Laboratory of the Manned Space Center.

VI. DEVELOPMENT OF DETECTORS USING LIQUIFIED 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 liquified noble gases.[1] Liquid argon is inexpensive, easy to handle, and after the passage of a minimum-ionizing particle provides copiuous quantities of free electrons even in layers as thin as 10 μm.

Our group has recently made the first observation of the fact that when electric fields in excess of 10^6 V/cm are present, these free electrons will avalanche, providing electrical signals as large as those produced by conventional gas-filled Geiger-Muller counters. We are now constructing a liquid-argon wire chamber with wire spacing 100 times smaller than the spacings used in conventional gas-filled wire chambers, in order to achieve a spatial accuracy in the neighborhood of 10 μm.

High Energy-Resolution Total-Absorption Counter

We have built and tested several liquid argon ionization chambers, the largest being a 4-in.-diam 2-in.-thick cylinder. A much larger chamber containing 12 cu ft of liquid argon is under construction and will be tested at the Stanford Linear Electron Accelerator. Such counters should prove to be far cheaper and much more available than equivalent quantities of NaI crystals.

VII. DATA-REDUCTION OPERATIONS

Edward H. Hoedemaker

A. EFFORT

The manpower level of the Scanning and Measuring Group dropped to an average of 67 full time equivalents, a reduction of 10% from the same 6-month period the year before.

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1. Luis W. Alvarez, The Use of Liquid Noble Gases in Particle Detectors with 1) High Spatial Resolution Over a Large Area, and 2) High-Energy Resolution as Total Absorption Counters, Group A Physics Note 672, November 26, 1968.

B. SCANNING

The scans receiving the greatest emphasis during this period were K82 (K^-p, 13 GeV/c, 82-inch bubble chamber), the backscattered laser experiment (γp, 3 and 5 GeV/c, 82-inch bubble chamber) $\pi 82$ (π^+p, 7 GeV/c, 82-inch bubble chamber), and two spark chamber experiments performed at the Bevatron. Many older experiments were also active, with most of their efforts being spent on special scanning jobs which defy quantitative reporting. For such scans, an asterisk replaces the number of frames in the table below to indicate the nature of the work. Six experiments were essentially completed during the period--$\pi 63$, P67, PD65, P67, $\pi 66B$, and $\bar{P}D$, while three new ones requiring scanning were begun--$\pi 82$, laser, and the N^*-decay spark-chamber experiment.

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

Scanning distribution

Experiment name (No.)	Frames of first production scan	Frames of second production scan	Frames of special scan	Scan effort (h)
APE(04)				
Conflict scan	---	---	---	41
Misc. special scans	---	---	---	23
APE totals				64
K72 (07)				
Ambiguities	---	---	---	108
K72 totals				108
$\pi 63$ (08)				
Vee'd events	---	---	10 831	---
Conflict scan	---	---	---	---
$\pi 63$ totals			10 831	150
K63 (12)				
Ambiguities	---	---	---	532
Operator rejects	---	---	---	229
Special η' study	---	---	---	114
K63 totals				875
KD63 (14)				
Ξ event types	---	---	---	203
KD63 totals				203

Scanning distribution (continued)

Experiment name (No.)	Frames of first production scan	Frames of second production scan	Frames of special scan	Scan effort (h)
π66A (18)				
Ambiguities	---	---	545	---
Twice-failing events	---	---	220	---
π66A totals			765	312
K65 (21)				
All event types except 2-prongs	2 880	---	---	12
Conflict scan	---	---	8 750	350
Other special scans	---	---	23 000	1 460
K65 totals	2 880		31 750	1 822
D66 (23)				
Special rescan	---	---	670	11
D66 totals			670	11
π66B (25)				
Ambiguities	---	---	579	---
Twice-failing events	---	---	512	---
66B totals			1 091	154
BP66 (26)				
Ambiguities	---	---	7 000	450
BP66 totals			7 000	450
K82 (30)				
All event types	292 233	---	---	3 162
All event types	---	51 625	---	536
Beam scan	---	---	20 800	225
Scanner checks	---	---	20 650	426
Conflict scan	---	---	20 155	582
Pulse-height scan	---	---	1 200	100
Other special scans	---	---	6 000	515
K82 totals	292 233	51 625	68 805	5 546

Scanning distribution (continued)

Experiment name (No.)	Frames of first production scan	Frames of second production scan	Frames of special scan	Scan effort (h)
π82 (32)				
All event types except two-prongs	74 596	---	---	633
All event types except two-prongs	---	6 500	---	59
Scanner checks	---	---	5 150	114
Pulse-height scan	---	---	2 620	320
π82 totals	74 596	6 500	7 770	1 126
η86 (34)				
All events	44 976	---	---	1 116
Scanner checks	---	---	3 082	185
Beam counts, other special scans	---	---	4 662	115
η86 totals	44 976		7 744	1 416
N^* Decay (35)				
All events	44 905	---	---	597
Special scans	---	---	---	100
N^* decay totals	44 905			697
Laser (37)				
All event types	99 000	67 000	---	---
Third production scan (all ET's)	---	---	5 700	---
Beam scan (e^- pairs)	---	---	2 700	---
Ambiguities	---	---	2 000	---
Laser totals	99 000	67 000	10 400	2 000
GROUP TOTALS	558 590	125 125	146 826	14 934

Breakdown of measurements by experiment.

Name (No.)	Description*	Number of events	
Bubble chamber experiments			
K72 (7)	K^-p, 72-inch	40	
K72D (14)	K^-n, 72-inch	2 312	
π66A (18)	π^+n, 72-inch	1 233	
K65 (21)	K^-p, 25-inch	47 612	
D66 (23)	DD, 72-inch	2 790	
π66B (25)	π^+p, 72-inch	745	
BP66 (26)	pp, 80-inch BNL	6 963	
LRL/SLAC (27)	π^-p, 72-inch and MURA	207 875	
K82 (30)	K^+p, 82-inch	229 810	
$\bar{p}$D (31)	$\bar{p}n$, MURA	87 568	
π82 (32)	π^+n, 82-inch	1 330	
DAVIS (33)	K^-p, 80-inch BNL	25 510	
Laser (37)	γp, 82-inch	4 849	
CERN (39)	$\bar{p}n$, 81-cm	58 473	
Total		677 110	
Spark-chamber experiments			
η86 (34)	π^-p, optic., n TOF	25 962	
N* Decay (35)	π^-p, optic., n TOF	30 008	
Total		55 970	
Total for group			733 080

C. MEASURING

A total of 677 000 bubble-chamber events were measured during this 6 months, an increase of 7% over the previous 6 months. The Mark II measuring projectors were utilized less than the previous 6 months, and the manpower scheduled on these machines will continue to drop in the future. We hope to modernize one or two of these devices by adding computer control. The aim would be to increase the output per man hour by a factor of three.

The breakdown of our measuring manpower by machine appears in the table below:

	Events	Measuring hours
MPII's:		
IIA	1 051	297.1
IIB	32 004	2 423.9
IIC	11 689	2 094.9
IID	9 265	1 939.8
All MPII's	54 009	6 755.7
Spiral readers:		
SRI	380 513	3 007.9
SRII	242 588	2 852.8
Both SR's	623 101	5 860.7
All machines	677 110	12 616.4

VIII. PROGRAMMING EFFORT

PERSONNEL

Barrie Pardoe
(supervisor of Group A programmers)

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

INTRODUCTION

From November 1968 through April 1969, the programming group has continued the maintenance and development of existing programs. Again emphasis has been placed on reducing core requirements (i.e., field length) and execution times of various programs. Increased effort was put into the Group A-Moyer-Helmholz collaboration, and support for the emulsion-spectrograph program was begun.

PROGRAMS

1. Data-Editing Programs

The new CDC 6600 program ORDER, for sorting strings of output data from any of the bubble-chamber programs was brought into use. The new ORDER uses the random-access capability of the disk file and requires a field length of about 75000_8 words (against 117000_8 for the older version) and is some 20% faster in execution.

MERGE-SELECT, for merging and selecting data strings, is being modified to include the new set of input-output routines to improve both field length and execution time.

2. Data-Analysis Programs

SIOUX, the combined three-view geometric-reconstruction and kinematic-fitting program for bubble chamber events, is being made to run under a more sophisticated FORTRAN compiler. This work is proceeding in two stages; the first is complete and has resulted in a decrease in execution time by about 20%. Further improvement is expected when the second stage is completed. The errors associated with effective masses calculated in the kinematic fitting of an event can now be included in the program output.

ARROW, the program used for selecting data from SIOUX for further processing, has had the unpacking/packing routines associated with the input/output routines completely rewritten. This resulted in a much simpler program with a field length reduced by 10000_8 words to less than 40000_8 and which is some 25% faster in execution than the previous version.

Modifications were also made to handle the effective-mass errors now available in SIOUX output.

3. Library-Function Programs

LYRIC, the main library program for Group A, has been improved by rewriting the unpacking/packing routines used when master lists are read and written. This has resulted in a 25% improvement in execution time.

The program has also been modifed to facilitate maintenance and operation.

4. Spiral-Reader Programs

Because the development of OAK, the PDP4 program for the spiral readers, is virtually complete, work was begun on the documentation. Work on the maintenance-diagnostic program OCTOPUS was continued.

POOH, the CDC 6600 pattern-recognition program which filters out events from spiral-reader data, has been improved. A completely new histogramming procedure has been written to deal with tracks near crutch points and is now running some ten times faster than the previous routine. This coding combines new binning methods with the processing of a smaller sample of data. The main histogramming routine now performs an initial fast pass which is supplemented in the REDO phase of the program should the event fail. Machine-coded fast tracking and finer-binned main histogramming have been coded and tested, but the final decision as to their usefulness has not been made.

For events that fail on the first pass, POOH now combines all of the tracks from the first pass with those of the REDO pass. This

allows REDO to be a supplementary heuristic process instead of an exhaustive somewhat redundant duplication of the first pass. With this basic structure now implemented, the initial gains in speed and accuracy should be multiplied many times as the heuristic codes improve.

A working version of SCOPE, the filter program used in conjunction with the vista console, has been written. Tracks are displayed in radius-theta coordinates and filtered by means of the light pen.

5. Spark-Chamber Programs

The modified DDP24-SASS programs[1] have been used to scan approximately 100 000 spark-chamber frames (events) for the Group A–Moyer-Helmholtz collaboration. The development of the program DHARMA for analyzing the SASS output data is progressing. So far around 30 000 events have been processed with a pass rate of 50 to 80 percent, depending on the number of electron showers in the event. Development of DHARMA will be continued.

A library program SCALP is being written for the collaboration.

6. Support Programs

The Berkeley Remote Facility, which is the outgrowth of the prototype COMUT, has been developed in conjunction with Math. and Computing into a multiprogrammed interactive system which provides access to the CDC 6600 from remote consoles. Its primary function is the solution of numerical problems, using a subset of the Fortran IV language. Current developments include an improved text editor, a compact storage-allocation system, expansion of the language to include subscripted variables and the DO statement, a facility for remote submission of programs, and a users' guide.

The OPTIME system for maximizing likelihood functions has been extensively recoded, resulting in a decrease in execution time by 25% and reduction in field length from $65\,000_8$ words to $50\,000_8$. Work is in progress to incorporate a "Las Vegas" routine to generate events according to a given distribution into the Monte-Carlo integration procedure so as to further decrease the execution time of the program.

UCRL-8030 is a compendium of particle properties and cross-section data collected from publications. Work is continuing on the program to plot cross-section data, and has resulted in improvements to printing and plotting formats.

A CRT-display text-generating and editing program is bein developed. When complete, it will be used for adding data to the UCRL-8030 compendium.

Emulsion Spectrograph Program work was begun on the PDP8 program to drive the Granite Stage when seeking tracks in the emulsion. Work has also begun on the CDC 6600 program for calculating the magnetic rigidity of tracks passing through the magnetic field of spectrographs.

Finally, a new set of input/output routines was written which provides increased flexibility and efficiency in handling input/output.

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

Programming Notes Written During this Period

Note No.	Date	Author(s)	Title
Algorithms A-1	Nov. '68	Barrie Pardoe	On Integer Division
--	Dec. '68	Ed Romascan	The Berkeley Remote Facility
		Jim Burkhard	User's Guide, Preliminary Edition
P-182	Dec. '68	Bruce Bailey	CALPLOT: A subroutine to plot data and functions on the Calcomp
P-183	March '69	Werner Koellner	A Users Guide to Optime
P-184	March '69	Philip Davis	K82 Version of Phony

IX. PARTICLE DATA GROUP

Arthur H. Rosenfeld, Naomi Barash-Schmidt,* Angela Barbaro-Galtieri, Odette Benary, LeRoy R. Price, Paul Soding,† and Charles Wohl

The January 1, 1969 edition in Reviews of Modern Physics ran 83 pages vs. 53 in 1968, mirroring the rate of increase of particle-physics data (see Fig. 1). To handle this increasing volume of data we have added two more authors who will collaborate on the next edition: one in Europe, one at LRL. The rate of compilation of cross-section data also continues to increase.

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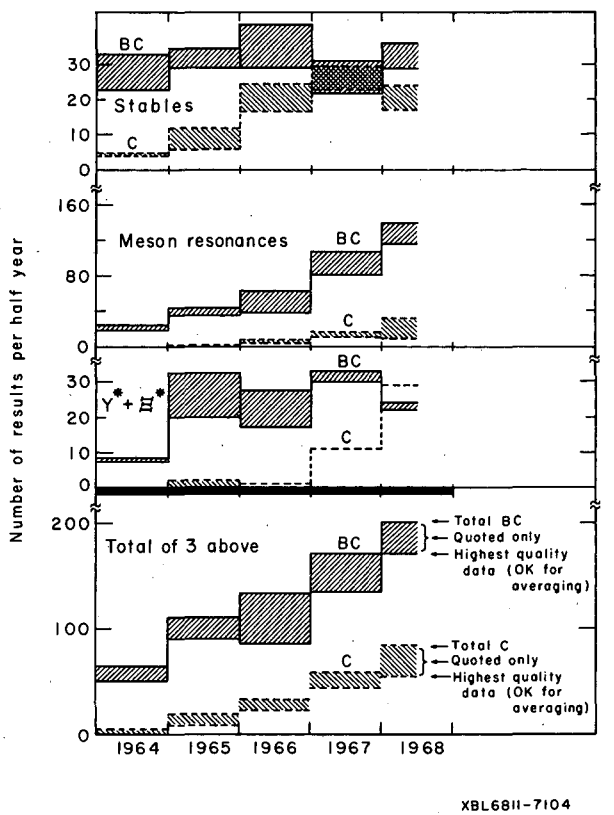

Fig. 1. Statistics on the increasing rate of production of data in particle physics. From the top to the bottom, the number of results per half year are presented for stable particles, meson resonances, $Y^* + \Xi^*$'s, and the total of three above. The full lines correspond to bubble chamber techniques (BC) and interrupted lines correspond to counters, spark chambers and mass spectrometers (C). Within each topic (stables, meson resonances, etc.) and for both techniques (BC and C) the lower lines correspond to highest-quality data (accepted for averaging and fitting) and the upper lines correspond to all the results (including those which we only quote). The dashed areas give the number of nonaveraged results.

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4. P. M. Dauber, J. P. Berge, J. R. Hubbard, D. W. Merrill, and R. A. Muller, Production and Decay of Cascade Hyperons, UCRL-18388, November 1968; to be published in Phys. Rev. 179.
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6. Stanley M. Flatte, Study of $\omega \rightarrow \pi^+\pi^-$ in $K^- p \rightarrow \Lambda\omega$ from 1.2 to 2.7 GeV/c, UCRL-18687, January 1969; submitted to Phys. Rev.
7. J. H. Friedman and R. R. Ross, Experimental Tests of the Quark Model Using the Reaction $K^- p \rightarrow \overline{K}^* \Delta$ at 2.6 GeV/c, Phys. Rev. Letters 22, 152 (1969).
8. R. D. Tripp, R. O. Bangerter, A. Barbaro-Galtieri, and T. S. Mast, Direct Evidence for the Multiplet Assignments of $\Lambda(1420)$ and $\Lambda(1405)$, Phys. Rev. Letters 21, 1721 (1968).
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EXPERIMENTAL PHYSICS

Kenneth M. Crowe and Donald H. Miller in charge

PION FORM FACTOR

Kenneth M. Crowe, Anthony S. L. Parsons, and Anthony Fainberg

Data reduction of the $\pi^{\pm}$ He^4 scattering experiment at the 184-inch cyclotron has been completed. The energies used were 51, 60, and 75 MeV. Various methods of calculating the Coulomb-nuclear distortion terms, are used to find the pion form factor. The value found for the rms pion radius is 2.96±.43F, which is larger than and in disagreement with the result predicted by vector-meson dominance. The result and its dependence on the optical-model potential used for the nuclear interaction are discussed in a paper published in Physical Review.[1]

π-π S-WAVE INTERACTION

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

The analysis of an experiment to study the pion-pion interaction in the S-wave, I-0 state is presently in progress. The presence of such a strong interaction between the final-state pions in the reaction, $\pi^- p \rightarrow \pi^0 \pi^0 n$, should exhibit itself in the energy distribution of the neutron. In the threshold region, the energy available to any final pion-nucleon system occurs much below the established isobar resonance states. Thus a pion-pion interaction might be expected to manifest itself as a dominant feature in the final state of the above reaction.

The basic experimental arrangement consists of an array of spark chambers to detect the γ rays from π^0 decays at the point of interaction with neutron counters at the end of a 20-ft flight path 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 performed at the 184-inch cyclotron in a collaborative effort with the University of California at San Diego was completed in May 1968. The program of film scanning and measurement of the showers in the γ chambers to provide event reconstructions is being concluded. Final analysis of the data 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 Berardo,† Roy P. Haddock,† Jerome A. Helland,† Bernard M. K. Nefkens,† Lynn Verhey,† and Michael E. Zeller†

The data-taking phase of this experiment was completed in October 1968. The neutron direction and time of flight were determined by use of 32 liquid scintillation counters with a spatial resolution of 0.25 msr each. A lead-plate spark chamber with scintillation counters embedded within it was used to detect the photon. Knowledge of the direction of the photon and the neutron as well as their time of flight allowed an event-by-event reconstruction under the assumption of the radiative mode. By this analysis we reject the background from charge exchange ($\pi^- p \rightarrow \pi_0 \eta$).

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* University of California, San Diego.

† University of California at Los Angeles.

Data were taken at the above energies at six photon c.m. angles between 40 and 150 deg, with the aim of attaining 3% statistical uncertainty at each point. In order to reach a similar level of uncertainty in the systematic errors, the energy-dependent neutron detection efficiency of the counters was measured in a n-p elastic scattering experiment.

The experiment was performed (1) to investigate the SU_3 classification of the Roper resonance, P11 (1460), (2) to determine the isotopic spin amplitudes for pion photoproduction, and (3) to measure the partial width of the radiative decay of the first resonance. To date, the only available data are from experiments using the inverse process ($\gamma n \rightarrow \pi^- p$) with a deuterium target. These data are limited due to the effects of the presence of the spectator proton, which must be calculated.

For the same incident energies a small fraction of the data-taking time was devoted to accumulating events in which the neutron alone was detected. Analysis of the neutron time-of-flight spectra allows the charge-exchange cross section to be deduced. The same c.m. angular range as above was covered. Preliminary results of these measurements have been presented at the New York and Washington APS meetings.

The experiment performed at the 184-inch cyclotron in a collaborative effort with the University of California at San Diego was completed in May 1968. The program of film scanning and measurement of the showers in the γ chambers to provide event reconstructions is being concluded. Final analysis of the data is presently in progress.

RADIATIVE CAPTURE OF STOPPED π^- MESONS ON NUCLEI

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

An experiment is being conducted to measure the energy spectrum of the high-energy γ rays following the capture of negative pions on various even-even nuclei, i.e., the process $\pi^- + N(A, Z) \rightarrow N(A, Z-1) + \gamma$. Recent theoretical calculations using PCAC and the impulse approximation for inverse pion photoproduction on bound nucleons have emphasized the similarity of the axial-vector matrix elements governing this process with the kinematically analogous muon capture. In the analysis of total muon capture rates it is evident that collective states of the residual nucleus are predominantly excited. The nature and location of these states is predicted, but widely unknown. The best known member of the multiplet is the $\Delta S = 0$, $\Delta T = 1$, $\Delta T_3 = 0$ isospin resonance or giant dipole state seen in photonuclear reactions. In muon capture the isospin states are also excited, but since neutrino spectroscopy is unaccessible, no comparison with the theory can be made. Pion capture is expected to proceed via the excitation of spin-isospin states with the selection rules $\Delta S = 1$, $\Delta T = 1$, $\Delta T_3 = \pm 1, 0$. This results in a fine structure of the γ-ray spectrum. The complete lack of experimental information, however, does not allow a check on the predictions at present, except for the total branching ratio for the radiative capture (approximately 2%).

Our apparatus has been designed to yield information on the branching ratios to the different excited states. This will allow a model-independent calculation of the axial-vector form factors, which then can be compared (assuming their dependence on the momentum transfer) with those obtained from muon capture and beta decay. A high-resolution, high-acceptance gamma-ray pair spectrometer has been constructed consisting of two 16- $\times$ 36-in. C magnets with common pole tips and an array of six optical spark chambers.

The field in the C magnet has been mapped and the momentum analysis programs are com-

plete. The spark chambers and associated equipment have been tested. The equipment has been set up in the meson cave of the 184-inch cyclotron in March 1968. During April and May 1969 data have been accumulated for the elements ^{16}O, ^{12}C, ^{4}He, ^{6}Li, and ^{24}Mg. Also a set of calibration data was obtained using a hydrogen target, confirming the expected properties of the pair spectrometer. The spark-chamber film is currently scanned on semiautomatic machines.

The experimental part will continue until July 1969.

MEASUREMENT OF THE DIFFERENTIAL CROSS SECTION FOR $\pi^- p \rightarrow n\gamma$ BETWEEN 500- AND 900-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 investigate the above process is presently running at the Bevatron. The apparatus corresponds closely to that used at the 184-inch cyclotron (see above), with small modifications to allow for the increased instantaneous beam rate the higher backgrounds expected.

The aim of the experiment is to explore the radiative decay mode of various pion-nucleon resonances in the mass range from 1400 to 1850 MeV. Several predictions, some contradictory, have been made for the neutral radiative decay of many of the resonances in this region. The measurements will take the form of angular distributions as well as excitation functions. Data for this process can be used to test the Dat-Weisskopf relationship relating photoproduction of pions and the production of ρ and ω mesons in $\pi^- p$ interactions. In addition to the inverse photoproduction experiment, we have proposed measuring charge-exchange and η-production differential cross sections in the regions where disagreements between experiments now exist. These experiments would be performed with the existing apparatus using neutron time-of-flight information.

*University of California at Los Angeles.

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

Donald H. Miller, Robert Budnitz, William Ross, Robert McCarthy, and Jesse Brewer

Using a neutral beam from the third focus of the Bevatron's external proton beam, we will measure the charge asymmetry in $K^0_{\mu 3}$ decay. We define the ratio R:

$$R = \frac{\text{Rate}(K^0_L \rightarrow \pi^- \mu + \nu)}{\text{Rate}(K^0_L \rightarrow \pi^+ \mu - \nu)} .$$

Any difference of R from unity is a direct indication of CP violation in the K_L decay.

The expectation is that about 10 million decays ($K_L \rightarrow \pi + \mu + \nu$) will be observed in the allotted running time. We expect to improve on the present experimental value for the charge asymmetry both by the increased statistical precision and by the ability to study in detail many possible systematic effects.

The experimental design allows the incident K mesons to decay in flight about 30 ft downstream of their production. The decays will occur in a large vacuum vessel; the vacuum is necessary to eliminate neutron interactions in the air otherwise present in the beam line. Pions and muons from the K_L decay are detected in a series of counter hodoscopes. Muons are separated from pions by differential range through a 36-in.-thick lead wall. The charge of the muon is determined by its curvature as it passes through the magnetic field of the M5 magnet (curvature measured by a succession of hodoscopes) and by the position of the muon after it is deflected; the magnet is strong enough to overcome the maximum transverse momentum received by the muon in the K_L decay.

The information from all of the hodoscope counters will be transcribed on to magnetic tape (for later reanalysis) using an on-line PDP-9 computer, which will also perform various checks and plot selected histograms for on-line monitoring.

Set-up on the Bevatron floor began in February 1969; tune-up and data taking are scheduled to begin in June 1969.

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3. Anthony S. L. Parsons, P. Truoel (LRL), P. Berardo, Roy P. Haddock, J. A. Helland, B. M. K. Nefkens, L. J. Verhey, and Michael E. Zeller (UCLA), Measurement of the Differential Cross Section for Pion-Proton Charge Exchange by 200-, 320, and 360-MeV Pions, Bull. Am. Phys. Soc. II 14, 108 (1969).
4. L. J. Verhey, P. Berardo, R. P. Haddock, J. A. Helland, B. M. K. Nefkens, M. E. Zeller (UCLA), Peter Truoel and A. S. L. Parsons (LRL), Measurement of the Differential Cross Section for $\pi^- p \rightarrow n\gamma$ at 200 and 320 MeV, I. Experimental Results, Bull. Am. Phys. Soc. II 14, 636 (1969).
5. Peter Truoel, A. S. L. Parsons (LRL), P. Berardo, Roy P. Haddock, B. M. K. Nefkens, L. J. Verhey, and M. E. Zeller (UCLA), Measurement of the Differential Cross Section for $\pi^- p \rightarrow n\gamma$ at 200 and 320 MeV, II. Analysis. Bull. Am. Phys. Soc. II 14, 637 (1969).

NUCLEAR EMULSION GROUP

Harry H. Heckman in charge

STOPPING-POWER DIFFERENCES BETWEEN POSITIVE AND NEGATIVE PIONS AT LOW VELOCITIES

Harry H. Heckman and Peter J. Lindstrom

The project has been completed and the results have been published in the April 28 issue of Physical Review Letters. To summarize briefly, we observed directly the differences in the energy-loss rates of stopping π^+ and π^- in emulsion. Ionization differences occur for velocities $\beta \lesssim 0.14$, with $(dE/dx)_+ - (dE/dx)_-$ becoming as large as 60 MeV/cm at $\beta = 0.051$, the lowest velocity we were able to examine. These observations fully account for the previously reported anomalous ranges of stopping π^- and Σ^- particles. This experiment gives direct evidence for a difference in the stopping power of positive and negative particles at the same velocities, when these velocities are comparable to those of the atomic electrons of the stopping media. Further investigations of this effect at lower velocities are planned.

LOW-ALTITUDE GEOMAGNETICALLY TRAPPED PROTONS*

Harry H. Heckman and G. H. Nakano †

The scanning of emulsions recovered from four polar-orbiting-satellite experiments carried out in 1968 is in progress. These data will augment our information on the solar-cycle variations of low-altitude trapped protons. These observations were initiated in late 1962 and have continued since then. During this time we have measured the proton flux, energy spectrum, east-west asymmetries in the directional flux, and their temporal variations.

PARTICLE IDENTIFIER*

Douglas Greiner, ‡ Richard Albert, ‡ and Harry Heckman

Fabrication of a flight-model particle identifier, based on the laboratory prototype described in the previous Semiannual Report, was begun during this report period. The identifier, an eight-element solid-state telescope, will be used on a Black Brant IV rocket flight to be flown to an altitude of about 900 km at the geomagnetic equator (Natal, Brazil). The purpose of the experiment is to study the energy spectrum $40 < E < 140$ MeV, flux, and pitch-angle distribution of trapped protons on geomagnetic shells $L \lesssim 1.20$ (in units of earth radii). Identification and measurement of the flux of particles heavier than protons will also be attempted.

HIGH-ENERGY NEUTRON-SPECTRUM MEASUREMENTS

Harry H. Heckman and H. Wade Patterson

The excitation function for the production of star prongs with ranges $\geqslant 2$ nm in nuclear emulsion by incident neutrons has been extended to neutron energies $E_n \approx 3$ GeV. The excitation function thus has been measured in the energy interval 27.5 MeV $< E_n < 3.0$ GeV, and will be used to determine the power-law exponent of neutron spectra in this energy range. The excitation measurements in this project have been completed, and specific applications of this technique to neutron monitoring have begun.

*This work was supported by the National Aeronautics and Space Administration.
†Lockheed Missiles and Space Company, Palo Alto, California.

‡Space Science Laboratory, University of California, Berkeley.

STUDIES OF TRACK FORMATION IN SOLIDS

Harry H. Heckman and Robert M. Walker‡

To study the mechanism of track formation in mica we have made x-ray measurements of mica irradiated with heavy ions from the Hilac. Samples irradiated with argon ions of 9.3, 7.6, 3.7, and 1.1 MeV/nucleon showed a linear dependence of the Laue spot asterism over most of the dose range from 9.0×10^{11} to 2.0×10^{13} ions/cm^2. No measurable asterism was found for neon and oxygen irradiations at doses of 10^{13}/cm^2 and 10^{14}/cm^2.

Natural crystals of feldspars, pyroxenes, quartz, and apatite were also irradiated with neon and argon ions of up to 10.2 MeV/amu, with maximum doses of 1.6×10^{13} argon ions/cm^2 and 4.0×10^{13} neon ions/cm^2 respectively. The samples were thinned to thicknesses near 30 microns, stacked to form the target and then bathed completely in the ion beams. X-ray and optical observations revealed: (a) a crystal distortion and curvature with the argon irradiation similar to that produced in mica, as described above; (b) a lesser effect from neon bombardment; (c) a fracturing of the crystal samples which depended on the total dose and energy of the incident ion; (d) polygonized structures produced when either neon or argon ions were trapped within the crystals. These data are relevant to the possible alteration of the lunar surface due to solar particles.

‡Washington University, St. Louis, Missouri.

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Harry H. Heckman and Peter J. Lindstrom, Stopping-Power Differences Between Positive and Negative Pions at Low Velocities, UCRL-18718, January 1969; Phys. Rev. Letters 22, 871 (1969).

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Harry H. Heckman, Stopping-Power Differences Between Positive and Negative Particles at Low Velocities, UCRL-19211, June 1969; Invited Paper, American Physical Society Meeting, Washington, D. C., April 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 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 will be complete when the effect of the downstream anticoincidence counter can be incorporated. Final data on the mass, Treiman-Yang angle, and π-π scattering-angle distributions should appear fairly soon, and limits of ~ 10 μb should be set for particle production where no peaks are seen. An abstract was submitted to the 1969 New York APS meeting.[1]

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

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 underway, and it is expected that about 1.2×10^6 events with scattering in the carbon plates will survive all the tests and cuts. Preliminary polarization data on p-p scattering agree with previous experiments. It is hoped that the bulk of the analysis will be complete by the end of the year.

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, ninety percent 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 one-third of the data have been scanned and measured. In the 1 percent of the data which has been completely analyzed, five 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.

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*Now at Argonne National Laboratory, Illinois.

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, Lawrence Radiation Laboratory Report UCRL-18603, November 1968.

†Now at Brookhaven National Laboratory, New York.

‡Visitor from Virginia Polytechnic Institute, Blacksburg, Virginia.

§ Now at Argonne National Laboratory, Illinois.

** Now at the University of Lancaster, England.

NEUTRAL LEPTONIC CURRENTS

Alan R. Clark, Tom Elioff, R. Clive Field, Henry J. Frisch, Rolland P. Johnson, Denis Keefe, Leroy T. Kerth, Martin H. Krieger, David Newton,* and W. A. Wenzel

The work described in the previous semi-annual report is approaching the stage of beam testing. The K^0 beam line of sweeping magnets and collimators has been installed at the third focus of the Bevatron external proton beam Channel 1. Construction of spark chambers, hodoscopes, Cerenkov counters, and the range-measuring systems is nearing completion, and testing is at an advanced stage on the components available. The two magnets have been surveyed, and the line integrals of the field are sufficiently uniform across the aperture for our purposes.

The fast electronics for triggering is also being tested, as is the data handling systems for the spark chambers. Programs for the PDP-9 computer have been developed and will soon be ready for use. Programs for preliminary analysis on the CDC 6600 are being prepared. It is hoped to commence data taking in July and to start analysis soon after.

*Now at University of Lancaster, England.

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EXPERIMENTAL PHYSICS

Burton J. Moyer and A. Carl Helmholz in charge

MEASUREMENTS OF THE BRANCHING RATIO $K_L^0 \to 2\pi^0/K_L^0 \to 3\pi^0$ AND DETERMINATION OF $|\eta_{00}|^2$

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

This experiment has reached a conclusion in the principal objective, yielding a value of 1.3% ± 0.2% (statistical) ± 0.24% (systematic) for the branching ratio.[1] The value of $|\eta_{00}|^2$ derived from this is $(14.5 \pm 3.1) \times 10^{-6}$, where the given uncertainty reflects both statistical and systematic errors. This result is evidence against the "superweak" theory as the means of accounting for the CP-violation observed in K_L^0 decay.

Six previously published values for $|\eta_{00}|^2$ range from $(-2 \pm 7) \times 10^{-6}$ to $(24 \pm 5) \times 10^{-6}$, although the highest of these has been withdrawn in favor of lower values subsequently obtained by the same investigator(s). The value required by the superweak theory is very close to 4.0×10^{-6}; thus the present result differs by about three standard deviations from that theoretical prediction.

The present method utilized an array of lead-plate spark chambers almost completely surrounding a 1 cubic meter volume through which a flux of K_L^0 mesons of known momentum passed. The neutral decays occurring within this volume were observed with high efficiency of solid angle and photon conversion, so that the prominent $K_L^0 \to 3\pi^0$ mode could be recognized about 95% of the time simply by observation of five or six showers in the spark chambers. The $K_L^0 \to 2\pi^0$ mode was identified by kinematical analysis, assisted by spark multiplicities observed in the showers.

Two separate methods of analysis gave consistent results. In one method the $2\pi^0$ final state was identified by calculation of the angle between the directions of the two π^0's assumed to give rise to the four showers. In the known K_L^0 rest frame this angle should be 180 deg in the absence of measurement uncertainties. The second method the use of kinematical constraints, assisted by spark counts, provided a calculation of the mass of the entity decaying into the four photons through the assumed $2\pi^0$ intermediate state. The distribution of mass values showed a peak at the K_L^0 mass, superimposed upon a background arising from 4-shower events due to $3\pi^0$ decays in which two photons escaped without producing visible showers.

The quantitative interpretation by either method utilized Monte Carlo representations of both background and "signal." The Monte Carlo program was based upon the behavior, in our chambers, of photons of known energies obtained by extensive operation of the experimental system in a mode to detect $K_L^0 \to \pi^+\pi^-\pi^0$, for which the energies of the showers arising from the π^0 decay could be calculated within close limits. Such interpretation of both methods of analysis indicated 132 ± 18 decays of the $2\pi^0$ mode were present in the data.

Other information about the K meson is inherent in data accumulated for the $K_L^0 \to 3\pi^0$

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*University of 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, A Measurement of the Branching Ratio $K_L^0 \to 2\pi^0/K_L^0 \to 3\pi^0$, UCRL-18845, April 14, 1969; submitted to Physical Review Letters.

events. This is under analysis with the goal of extracting an understanding of the momentum dependence of the matrix element governing this decay interaction.

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

Brownlee Gauld, Victor Perez-Mendez, Robert J. Cence,* Brian D. Jones,* Richard Morgado,* Vincent Z. Peterson,* and Leroy Shiraishi*

This experiment is set up and running at the Bevatron. All hardware is in place. Testing and final beam tuning has yet to be completed. Data taking should begin about May 15 and terminate by September 1.

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 the last Physics Semiannual Report). An article dealing with the liquid-deuterium Cerenkov counters and our measurements of the refractive index of liquid deuterirum will be published in Physica shortly.[1]

Work is continuing on beam design for Bevatron Expt. 105, which will extend our experimental testing of CPT invariance by comparing the lifetimes of K^+ and K^- mesons.

*University of Hawaii.
†University of California, Santa Barbara.
‡Tufts University, Medford, Massachusetts.
1. D. S. Ayres, A. M. Cormack, A. J. Greenberg, R. W. Kenney, D. O. Caldwell, V. B. Elings, W. P. Hesse, and R. J. Morrison, A Determination of the Refractive Index of Liquid Deuterium Using the Cerenkov Effect, UCRL-18567, November 1968; to be published in Physica.

μ^- CAPTURE NUCLEAR γ-RAYS

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

The first results of the O^{16} measurements have been published.[2] We presented a preliminary analysis and interpretation of the large Doppler broadening observed in the γ ray from the 6.323-MeV level of ^{15}N at the Miami meeting of the American Physical Society in November 1968.[3] Final analysis of the Doppler-broadened line shape is not yet completed. The results to date are all consistent with μ^- capture occurring primarily through a resonance nuclear-excitation process.

A study of particle-hole excitations of nuclei induced by μ^- capture has just started at the 184-inch cyclotron. The first nuclei that will be investigated are ^{40}Ca and ^{32}S.

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 hopefully will rectify the present disagreements among existing branching-ratio

2. S. N. Kaplan, R. V. Pyle, L. E. Temple, and G. F. Valby, Phys. Rev. Letters 22, 795 (1969).
3. S. N. Kaplan, R. V. Pyle, L. E. Temple, and G. F. Valby, Bull. Am. Phys. Soc. 13, 1424 (1968); presented at the Fall meeting, American Physical Society, Miami Beach, Florida, November 25-27, 1968.
§Group A.

measurements. Film analysis is currently under way. An abstract covering preliminary results has been submitted to the Lund International Conference on Elementary Particles.[1]

The second experiment is also complete through the running stage. The reactions $\pi^- p \to N_{1/2}^*(1680) \to \eta n$ and $\pi^- p \to N_{1/2}^*(1688) \to \eta n$ are being looked for in the film analysis. There exists an SU(3) prediction of 0.3 mb for an ηn final state via either $D_{15}[N^*(1680)]$ or $F_{15}[N^*(1688)]$ intermediate states. Neither reaction has been observed prior to our work, and our analysis is 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 has been submitted to the Lund International Conference on Elementary Particles.[2]

The third experiment in this series is scheduled to begin in early July, and preparations are under way to meet the schedule. It is a relatively complete study of the $\pi^0\pi^0$ system in the reaction $\pi^- p \to \pi^0\pi^0 n$.

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

The existing spark-chamber array has been used without rearrangements to data, 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 is required, and the neutron counters must be reoriented. These changes are now under way. No alteration of the spark-chamber array is required.

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*

Data runs on the photoproduction of ρ^0 mesons in a photon beam produced by the bremsstrahlung of 16-GeV electrons were completed in February 1969. The data include ρ^0 production cross sections from hydrogen, deuterium, beryllium, and lead, as well as cross sections for the photoproduction of other high-mass dipion states.

The final results for the photoproduction of ρ^0 mesons from solid targets at 9 GeV was published in Physical Review Letters.[3] The data on photoproduction at 5 and 7 GeV from solid targets and at 9 BeV from hydrogen are currently being prepared for publication. In these reports we show that the ρ-N total cross section is 30 ± 5 mb at 9 GeV, and from the application of the vector dominance model, we obtain a value for the rho-photon coupling constant of $\gamma_\rho^2/4\pi = 1.1 \pm 0.2$.

1. T. B. Risser, M. A. Wahling, M. Pripstein, J. E. Nelson, I. R. Linscott, R. W. Kenney, R. D. Eandi, O. I. Dahl, and R. B. Chaffee, A High Statistics Study of the Neutral Decay Modes of the η Meson, UCRL-18851 Abstract, April 1969; submitted to the Lund International Conference on Elementary Particles, June 25-July 1, 1969, Lund, Sweden.
2. R, B. Chaffee, J. E. Nelson, O. I. Dahl, R. W. Kenney, I. R. Linscott, M. Pripstein, T. B. Risser, M. A. Wahlig, D. S. Ayres, and A. Skuja, A Search for the Decay $N_{1/2}^* \to \eta + n$ in the 1688-MeV Region, UCRL-18852 Abstract, April 1969; submitted to the Lund International Conference on Elementary Particles, June 25-July 1, 1969, Lund, Sweden.

*Stanford Linear Accelerator Center, Stanford, California.

3. R. Bulos, W. Busza, R. Giese, R. R. Larsen, D. W. G. S. Leith, B. Richter, V. Perez-Mendez, A. Stetz, S. H. Williams, M. Beniston, and J. Rettberg, Phys. Rev. Letters 22, 490 (1969).

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

The angular distribution of the reaction $n + p \rightarrow \gamma + d$ was measured at incident neutron energies spanning the N*(1238) resonance to compare 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 data now analyzed (20%) indicates a disparity ($\chi^2 = 8.5$, expecting $\chi^2 = 4$) in the angular distributions for the reactions $n + p \rightleftarrows \gamma + d$. Another measurement of the distribution performed at the Princeton-Pennsylvania Accelerator by a Princeton group yields a similar disparity, although their measurement of it is presently larger than our measurement.

Current efforts are devoted to removal of systematics from the analyzed sample and to completion of the analysis of the remaining data (80%). These efforts should be completed by September 1969.

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

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

The experimental run in the meson cave of the 184-inch cyclotron has been completed. We are proceeding with the analysis of the data. An interaction between the three neutrons in the final state of the reaction $\pi^- + {}^3He \rightarrow \pi^+ + 3n$ would distort the energy distribution of the three-neutron system from that given by simple phase space. Such an interaction was indicated in our previous $\pi^- - {}^4He$ experiment. In addition, we are looking for states for ${}^3He$ and ${}^4He$ which are excited by negative pions.

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 is scheduled to begin at the 184-inch cyclotron in July 1969. The experiment uses magnetostrictive spark chambers to measure the vector momentum of the two electrons in the decay $\pi^0 \rightarrow e^+e^-\gamma$. It is anticipated that about one million events can be collected in 200 hours running time, and that the slope of the form factor can be determined to within 1%.

A number of publications are also listed for previously completed experiments.[1-5]

INSTRUMENTATION

Ronald L. Grove,‡ Gerald L. Stoker,‡ Alexander Rindi,§ Harold Wollenberg,§ and Victor Perez-Mendez

We continued work on the sparkostriction readout method for use with wire chambers in magnetic fields and on developments for

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*University of California, Los Angeles, California.
†University of Michigan, Ann Arbor, Michigan.

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2. A. W. Stetz, V. Perez-Mendez, and J. Sperinde, Polarization in Proton-Helium Scattering at 70 and 80 MeV, UCRL-18504 Abstract, October 1968; paper presented at APS Meeting, San Diego, December 1968.
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‡Electronics Group.
§Health Physics Group.

improving the readout for large wire chambers.[1] We also have continued to work on evaluating the performance of wire spark chambers for use in medical diagnostics in locating the distributions of radioactive sources that emit single uncorrelated γ rays and from positron emitters.

In the single-γ mode detection--using a multihole lead collimator for defining the direction of the γ rays--we have measured the resolution as a function of γ energy and collimator characteristics. We have also investigated methods by which the rate and efficiency of those chambers as γ detectors can be improved. Since for high-energy work it would be advantageous to have wire chambers with higher accuracy of track location, we have started to consider the feasibility of using amorphous or microcrystalline semiconductors as the dielectric in place of a gas.[2] A solid dielectric "wire chamber" would also have some advantages in γ-ray detection for physics and medical projects.

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10. A. W. Stetz and V. Perez-Mendez, Development of a Helium-Filled Streamer Chamber System, UCRL-16891 Rev., March 1969; to be published in Nucl. Instr. Meth.
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EXPERIMENTAL PHYSICS

Wilson M. Powell and Robert W. Birge in charge

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

James Louie, George E. Kalmus, and Giovanni Borreani

We are analyzing production angular distributions and polarizations in the above reaction at six incident π^+ momenta between 1.34 and 1.85 GeV/c, representing the c.m. energy range 1850 to 2090 MeV. 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 not put into the s-channel, and t- and u-channel exchanges constitute the "background" amplitudes. Our main conclusion thus far is that no good solution can be found without an F37 resonant amplitude. We find the branching ratio of this amplitude into $K^+\Sigma^+$ to be $3 \pm 1\%$. Part of the data, from 120 000 pictures taken in the 72-inch bubble chamber, was presented at Vienna;[1] the expanded data, including 350 000 pictures taken in the 25-inch bubble chamber, were presented at the New York APS meeting, February 1969.[2] Exposures at four more energies are presently being made at the Bevatron.

K^-d and K^-n ELASTIC SCATTERING

George E. Kalmus and Nathan Jew

The study of the reaction $K^-d \rightarrow \pi^- p \Lambda$, where the proton momentum is greater than 0.25 GeV/c, was completed.[1] Work on the K^-d elastic scattering and the $K^-d \rightarrow K^-pn$ reaction continues. We found that the formalism for the breakup reaction as given in Ref. (2) has to be modified to take into account Fermi momentum smearing.

ANALYSIS OF THE REACTION $\pi^+p \rightarrow \pi^+\pi^+n$ AT 1.34-, 1.42-, AND 1.68-GeV/c INCOMING MOMENTA

Jack Sahouria

A total of 107 000 two-prong π^+p interactions at 1.34, 1.42, and 1.68 GeV/c were measured on the FSD machine.[3] Approximately 8% of these fit the reaction $\pi^+p \rightarrow \pi^+\pi^+n$. This reaction is being analyzed along the lines of the isobar model in a manner similar to the analysis of the reaction $K^-p \rightarrow \Lambda\pi^+\pi^-$ that was recently done.[4] We assume that the $N^*(1238)$ and the $N^*(1520)$ are coherently produced between the neutron and either of the pions in the final state, i.e., $\pi^+p \rightarrow N^*(1238) + \pi^+ \rightarrow n\pi^+\pi^+$ and $\pi^+p \rightarrow N^*(1520) + \pi^+ \rightarrow n\pi^+\pi^+$. This analysis is in the initial stages. The computer program that fits the model to the data is nearly complete.

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RESONANCE PRODUCTION IN π^+p INTERACTIONS

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

I. In a continuing study of the ρ-exchange model for the reaction $\pi^+p \rightarrow \pi^0\Delta^{++}$, we have measured 45 000 two-prong events from an exposure of the 25-inch bubble chamber to a 2.7-GeV/c incident π^+ beam. The automatic ionization measurements available from the FSD machine were used extensively. This supplements the 96 000 events between 3 and 4 GeV/c already discussed.

The dip in $d\sigma/dt$ near $t = -0.5$, characteristic of the ρ trajectory passing through zero at this point, is clearly observed. In addition, a second minimum near $t = -2.5$ is observed, thought to correspond to the second zero of the Regge amplitude. We also observe a backward peak which was not present in the 3- to 4-GeV/c data. Since 2.7 GeV/c is also the position of the N*(2420) resonance, the backward peak can also be interpreted as due to the $\Delta^{++}\pi^0$ decay of this resonance giving $X_{\Delta\pi} \simeq 0.05$. Arguments can be made to show that u-channel effects are negligible. Thus this reaction is an example of duality between t-channel exchanges and s-channel resonances as discussed by Schmid.

Fits are made to $d\sigma/dt \simeq P_{lab.}^{-2}[(s-u)/2]^{2\alpha(t)}$ to determine $\alpha_\rho(t)$, and the results are in substantial agreement with the ρ-trajectory parameters determined from the π^-p charge-exchange reaction.

The Ringland-Thews test for exchange of a single trajectory, $\rho_{33}\rho_{11} - (\mathrm{Re}\,\rho_{31})^2 - (\mathrm{Re}\,\rho_{3-1})^2$, has been made. A violation at small momentum transfers is seen at 3 to 4 GeV/c and 8 GeV/c, but none is observed in the 2.7-GeV/c data.

II. The A_2 trajectory is often thought to be degenerate with the ρ trajectory. To measure its parameters, we are studying the reaction $\pi^+p \rightarrow \eta^0\Delta^{++}$ at several energies from threshold to 4 GeV/c, using four-prong events. The production angular distributions at all energies are characterized by a dip in the forward direction, comparative flatness up to a t of about -0.6, and then a rapid fall off. A fit to the 3- to 4-GeV/c and 8-GeV/c data gives

$$\alpha_{A_2}(t) = (0.68 \pm 0.29) + (1.70 \pm 0.78)t.$$

The Δ^{++} decay density matrix elements are characteristic of an M1 transition at both the $p\Delta\rho$ and $p\Delta A_2$ vertices.

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

Robert W. Birge and George E. Kalmus

Scanning and measuring of about 100 000 two-prong events at 1.52, 1.73 and 1.84 GeV/c has recently been completed. Analysis of these data together with the 100 000 events previously measured at 1.34, 1.43, and 1.68 GeV/c has started. This work is in collaboration with a group at University of California, Riverside.

K^-p EXPOSURES

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

Several event types from this run have been scanned and measured on the COBWEB system. The two-prong-plus-vee channel has been used to determine the beam momenta for each of eleven different momentum settings. The events are being cleaned up for future analysis.

The scanning and measuring of event types with a decay kink (sigmas) has been carried out for six different momenta. The cleanup of events and analysis are just beginning.

DATA REDUCTION

Robert W. Birge and P. Wes Weber

With an average of 20.0 (full-time equivalent) visual-measurement personnel, the following data reduction was accomplished in the past six months.

Scanning

Experiment	Bubble chamber	Beam	Number of frames
COBWEB system			
42-44	72-inch hydrogen	1.35 to 1.68-GeV/c π^+	129 541
45-47	25-inch hydrogen	1.25 to 1.85-GeV/c π^+	782 769
50-52	25-inch hydrogen	1.1 to 1.6-GeV/c K^-	448 398
53-55	25-inch hydrogen	2.3 to 2.7-GeV/c π^+	36 563
		Subtotal	1 397 271
FSD system			
45-47	25-inch hydrogen	1.25 to 1.85-GeV/c π^+	81 630
50-52	25-inch hydrogen	1.1 to 1.6-GeV/c K^-	45 629
53-55	25-inch hydrogen	2.3 to 2.7-GeV/c π^+	272 043
		Subtotal	399 302
		Total	1 796 573

Measuring

COBWEB system	Measuring hours	Number of events	Events per measuring hour
(1 measuring microscope, 2 MP1-type Franckensteins)	3 078	56 354	18.3
FSD system			
(2 SP5B-type image-plane digitizers)	4 157	98 526	23.7
	7 235	154 880	

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EXPERIMENTAL PHYSICS

Emilio Segrè and Owen M. Chamberlain in charge

ANTIPROTON-PROTON INTERACTIONS

Ronnie Burns,* Paul Condon,*
Mark Mandelkern,* Jonas Schultz,*
William Chinowsky, and William R. Gage

We continue to analyze $\bar{p}p$ interactions. Cross sections for the various topologies have been measured at each of six beam momenta. There is an indication of structure in the four-prong cross section which is being investigated.

Differential cross sections for elastic scattering have been measured at each momentum. We continue to investigate structure in the backward elastic scatters, however, as well as the two-meson annihilations in order to determine resonance production and dynamical effects in these rare processes.

We have begun to study multipion annihilations. We observe strong ρ production in the $\bar{p}p \rightarrow 3\pi$ channel as well as abundant production of ω, ρ, X^0, A_2, and η in the four- and five-pion final states. There is an indication of structure in the R region in $\bar{p}p \rightarrow 5\pi$.

Events with K^0's are almost completely processed and show abundant K* production.

LOW-ENERGY π^-p INTERACTIONS

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

Measurement and data reduction have been completed for the 456-, 500-, and 552-MeV/c π^-p interactions in the Saclay liquid-hydrogen bubble chamber. The measured cross sections, at 552-MeV/c incident momentum, are 3.7 ± 0.3 mb for $\pi^-\pi^+n$ and 9 ± 0.2 mb for $\pi^-\pi^0p$. Distributions in effective mass and production angles are being fitted with prediction of an isobar model. Partial-wave amplitudes for the processes $\pi p \rightarrow \pi N^*$ and $\pi p \rightarrow \sigma N$, at each incident momentum, will result from the fits. Good fits to the effective mass spectra with large πN^* $P_{1/2}$ production amplitude require $\pi\pi$ T = 0 interaction (σ-meson production). These fits show $P_{1/2}$ and $D_{3/2}$ production amplitudes increasing with incident pion energy. The process of fitting to determine best values for the production amplitudes and some measure of their precision is continuing.

Measurement of the interactions at 580 MeV/c continues at approximately 1200 events per week. Some 6000 of an expected total of 20 000 have been completed. There will result some 5000 $\pi^-\pi^+n$ events and 2000 $\pi^-\pi^0p$ events.

MEASUREMENT OF K^--MESONIC X-RAY SPECTRA OF MEDIUM AND HEAVY ELEMENTS

Clyde E. Wiegand

Lines of the kaonic x-ray spectra of 24 elements ranging from Z = 17 to Z = 92 have been measured. Kaons are absorbed at the nuclear surface from circular orbits. The sudden cutoff of transitions to successively lower principal quantum numbers at certain values of Z indicates that nuclear matter (probably neutrons) extends above the conventional nuclear surfaces. A peak in one of the spectra corresponds to x rays from Σ^--hyperonic atoms. This work is continuing.

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

PIONIC ATOMS

Raymond Kunselman and Georges-André Grin*

The results of the measurements of chemical effects on the intensities of the x-ray lines in compounds is prepared for publication and is being given at the American Physical Society Meeting in Washington, April 28, 1969.[1] The measurements on the strong-interaction line shifts and widths in Ca^{40}, Ca^{44}, Th^{232}, and U^{238} are being prepared for publication.

The study of the pionic atoms has been presented as a thesis by Raymond Kunselman[2] and includes the recent work.

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

Donald Brandshaft, Roger Hildebrand,† Joseph Klems,† Rae Stiening, and Clyde Wiegand

We have prepared a counter-spark-chamber experiment to search for the reaction $K^+ \rightarrow \pi^+ \nu\bar{\nu}$. This process appears to offer the best opportunity to observe interactions involving hadrons and neutrino pairs.

The purpose of the experiment is to identify pions from $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ by observation of π-μ-e decays where the pions have ranges greater than those from $K^+ \rightarrow \pi^+\pi^0$. Processes involving high-energy gamma rays are suppressed by use of a high-efficiency Cerenkov counter. The $\pi^+\nu\bar{\nu}$ mode should be observed if it occurs as often as about once in 10^5 K^+ decays.

The entire detection system has been set up in the Bevatron building since March. The electronic racks are in their final location and we are simply waiting until the machine schedule will permit us to move the counter-spark-chamber assembly into the stopping K^+ beam. Tests of the apparatus have shown that all components operate satisfactorily. We find that the neutron background in the K-beam enclosure is far below the level that would interfere with the experiment.

We have tested the analysis procedures on μ-e decays using stray particles from the Bevatron.

POLARIZATION IN π^+p AND π^-p ELASTIC SCATTERING FROM 250 TO 410 MeV

William Gorn, Charles Morehouse, Thomas Powell, Peter Robrish, Stephen Rock, Stephen Shannon, Herbert Steiner, and Howard Weisberg

The polarization parameter in both π^+-p and π^--p scattering has been measured, using a polarized proton target, at four beam energies between 250 and 410 MeV. Analysis of the data is now complete and shows some discrepancies with earlier measurements. A phase-shift analysis will be undertaken to see if these new results make any appreciable changes in the existing phase-shift solutions in this energy range.

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

During the past six-month period, we have finished the running of the experiment at the Bevatron. A preliminary analysis of the data is about half completed. A general feature of the data is that the polarization rises rapidly,

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*On leave from Institute de Physique Nucleaire, Université de Lausanne, Switzerland; presently at the Swiss Embassy, Washington, D. C.

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†On leave from Department of Physics, University of Chicago, Chicago, Illinois.

‡Physics Department, University of Michigan, Ann Arbor.

moving away from the backward direction, and then levels out after about u = -0.03.

In March 1969, the run at the Bevatron was finished. The polarized proton target, consisting of a set of single crystals of lanthanum magnesium nitrate, performed well. Because of some lack of reliability in the instrumentation for recording the amount of target polarization, part of that circuity has been rebuilt. The whole apparatus performed quite well, and some preliminary results, based on part of the run, were reported by Howard Weisberg at the New York meeting of the American Physical Society. We expect the final results to give values for the polarization in backward n-p scattering to an accuracy of about 0.05, in favorable cases, for several incident neutron momenta between 3 and 6 GeV/c, between the values -0.03 and -0.6 for the invariant momentum-transfer variable u. The preliminary results show the polarization fairly independent of energy and angle in most of the region studied, with a value near -0.25 ± 0.10.

SEARCH FOR T VIOLATION IN INELASTIC e-p SCATTERING

Owen Chamberlain, Michel Borghini, Les Cotrell,* John Litt,* Luke Mo,* Charles Morehouse, Thomas Powell, Peter Robrish, Stephen Rock, Stephen Shannon, Gilbert Shapiro, Richard Taylor,* and Howard Weisberg

Experience has been gained with the horizontal (Roubeau type) cryostat, and a small fault that lead to poor efficiency of one heat exchanger has been found and corrected. The cryostat reaches below 1°K with no applied heat load, and operates as expected with a heat load. Work has been oriented toward a butanol-water-porphyroxide mixture because of the belief, based on CERN experience, that the butanol mixture is more reproducible than one based on ethanol. The polarized target has been moved to the SLAC Laboratory and installed at the pivot of the spectrometer, where it is operating. The target polarization is 30 to 33 percent before it has been exposed to any irradiation by the SLAC electron beam. The polarizable mixture is contained in small bags similar to small air mattresses. In this sort of bag the mixture freezes to small bars about 3 mm in diameter. The radiation resistance is satisfactory inasmuch as it can stand 4×10^{14} electrons per cm^2 before the initial polarization is reduced by a factor of e. We hope that this figure can be raised somewhat by changing the water fraction, and changing the amount of dissolved oxygen in the sample. To more or less double the practical life of the target, it can be annealed by heating for a few minutes to above liquid-nitrogen temperature. The target material will still be changed once each day. The data-taking stage should be reached in a few weeks.

*Stanford Linear Accelerator Center, Stanford, California.

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ATOMIC BEAM GROUP

Howard A. Shugart in charge

STUDIES IN LOW-ENERGY NUCLEAR AND ATOMIC PHYSICS

The numerous projects underway by members of the Atomic Beam Group encompass may facits of physics including weak interactions, nuclear properties and structure, and atomic physics. While some of our work involves the measurement of properties of stable and radioactive atoms by well-established methods, we maintain a continuous exploratory effort to devise new techniques and new experiments for testing fundamental physical laws. In this pursuit, the methods of optical or electron pumping and atomic beams play an important role in providing an essentially "free atom" environment for the systems under investigation.

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

1. Time Reversal Invariance in the β Decay of Ne^{19}; D. C. Girvin, F. P. Calaprice, and E. D. Commins.
2. Effect of Weak Interaction on the Strong Interaction; M. K. Simmons and E. D. Commins.
3. Isotope Shifts and Atomic Stark Effect in Stable and Radioactive Atoms; J. Yellin and R. Marrus.
4. Lifetime of Metastable Electronic States; R. S. Van Dyck, Jr., C. E. Johnson, and H. A. Shugart.
5. Lamb Shift by Quantum Beats and Related Phenomena; T. Hadeishi.
6. Coherence Effects in He; E. C. Geneux.
7. Xenon g Factors in Metastable Electronic States; C. E. Johnson.
8. Fine Structure of Helium-Hyperfine Structure in He^3; C. E. Johnson.
9. N. M. R. of Radioactive Xe Isotopes; J. J. Huntzicker.
10. Search for a Possible Electron Mass Shift; J. R. Mowat, C. E. Johnson, and H. A. Shugart.
11. Spins and Moments of Radioactive Germanium Isotopes; A. F. Oluwole and S. G. Schmelling.
12. Spins and Moments of Radioactive Thulium Isotopes; S. G. Schmelling.
13. Spectrum of a Free Radical of Interest to Radioastronomers; B. D. Zak, S. G. Schmelling, and H. A. Shugart.
14. Universal Mass Spectrometer Detector for Atomic Beams; B. D. Zak.
15. Computations in Nuclear Structure; A. A. Ross-Bonney.

The activity of the group during the past six months can be indicated by enumeration of the published papers or reports which have appeared:

PUBLICATIONS AND PAPERS

Abstracts

1. C. E. Johnson, M. H. Prior, and H. A. Shugart, Hyperfine Structure of g_J of ^{129}Xe in the $5d[3-1/2]_4$ State, UCRL-18709 Abstract, January 1969; Bull. Am. Soc. 14, 524 (1969).
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3. Anne A. Ross-Bonney, Shell Model Calculation for Nonclosed Shells, UCRL-18736 Abstract, February 1969; Bull. Am. Soc. 14, 626 (1969).
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8. E. C. Wang, R. Marrus, and J. Yellin, Measurement of the Isotope Shifts in the D_1 Lines of ^{127}Cs, ^{129}Cs, ^{133}Cs, ^{134}Cs, ^{134m}Cs, and ^{137}Cs, UCRL-18513 Abstract, October 1968; Bull. Am. Phys. Soc. 13, 1650 (1968).
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Papers

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2. F. P. Calaprice, E. D. Commins, H. M. Gibbs, G. L. Wick, and D. A. Dobson, Test of Time Reversal Invariance and Measurements of Positron and Neutrino Asymmetries in Polarized ^{19}Ne Beta Decay, UCRL-18647, January 1967; submitted to the Phys. Rev.
3. Tetsuo Hadeishi, Observation of Resonance Effect in Modulated Fluorescent Light from Coherently Excited $4\,^2P_{1/2}$ and $4\,^2P_{1/2}$ Levels in $^4He^+$, Phys. Rev. Letters 22, 815 (1969).
4. R. Marrus and J. Yellin, Electric Polarizabilities of the $4\,^2P$ Level of Potassium, UCRL-18354, July 1968; Phys. Rev. 177, 127 (1969).
5. R. Marrus, E. C. Wang, and J. Yellin, Atomic Beam Measurement of Isotope Shifts in the D_1 Line of ^{127}Cs, ^{129}Cs, ^{133}Cs, ^{134m}Cs, ^{134}Ca and ^{137}Cs, UCRL-18349, July 1968; Phys. Rev. 177, 122 (1969).

Invited Paper

1. Tetsuo Hadeishi, Lamb Shift Observation by Temporal Variation of Resonance Fluorescence, UCRL-18641, December 1968; Bull. Am. Phys. Soc. 14, 103 (1969).

EXPERIMENTAL PHYSICS

George H. Trilling and Gerson Goldhaber in charge

POLARIZATION IN K^+p ELASTIC SCATTERING AT 864 MeV/c

Roger W. Bland and John M. Hauptman

Previous semiannual reports have described the analysis of K^+p interactions at 864 MeV/c. We have rescanned 10 000 elastic scattering events for events with a secondary scatter. About 400 such events were found, 250 of which corresponded to the reaction

$$K^+p \rightarrow K^+p$$
$$\hookrightarrow pp \rightarrow pp.$$

From a study of the azimuthal distribution of the secondary scattering plane we find that the proton polarization can be represented by

$$P(\theta) = P_0 \sin\theta,$$

with $P_0 = 0.7 \pm 0.4$. A paper on this analysis is now being written.

K^+p INTERACTIONS AT 9 GeV/c

Gideon Alexander, Alexander Firestone, Chumin Fu, Gerson Goldhaber, V. Gordon Lind, and David A. Lissauer

We have continued the study of ~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. The work published thus far is summarized in Refs. 1 through 7. In addition, work has proceeded on five additional projects, discussed below, two of which are in the final stages of publication as shown in Refs. 8 and 9.

We have studied the five- and six-body final states $K^0p\pi^+\pi^+\pi^-$ and $K^0p\pi^+\pi^+\pi^-\pi^0$ and have found (1) strong A_1 meson production in these final states which argues against a simple Deck-type interpretation for the A_1 meson; (2) an explanation for the $\kappa(720)$ enhancement as a reflection of the Δ^{++}_{1236} in these final states; and (3) a possible new K^* resonances at mass 2640.[8]

We have continued our study of the low-mass $K\pi\pi$ enhancement, called the Q, in the four-body final states $K^+p\pi^+\pi^-$ and $K^0p\pi^+\pi^0$.

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1. G. Goldhaber, A. Firestone, and B. C. Shen, Evidence for $K^*(1250)$ Resonance Production in K^+p Interactions at 9 BeV/c, Phys. Rev. Letters 19, 972 (1967).
2. B. C. Shen, A. Firestone, and G. Goldhaber, Antixi Production in K^+p Interactions at 9 GeV/c, Phys. Letters 25B, 443 (1967).
3. G. Goldhaber, Interference Phenomena Associated with Boson Resonance Production, Phys. Rev. Letters 19, 976 (1967).
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6. G. Alexander, A. Firestone, and G. Goldhaber, Search for S = 2 Boson Resonances in the Mass Region of 1.0 to 3.1 GeV, Phys. Letters 27B, 177 (1968).
7. G. Alexander, A. Firestone, C. Fu, G. Goldhaber, and A. Pignotti, Double Regge Description of ω Production in K^+p Interactions, Phys. Rev. 177, 2092 (1969).
8. G. Alexander, A. Firestone, and G. Goldhaber, Resonance Production in Multi-Particle Final States in K^+p Interactions at 9 GeV/c, UCRL-18786, February 1969; to be published in the Phys. Review.
9. G. Alexander, A. Firestone, G. Goldhaber, and D. Lissauer, Decay Analysis of the Low-Mass $K\pi\pi$ Enhancement into K^*_{890} and π-π Systems, UCRL-18872, May 1969; submitted to Phys. Rev. Letters.

With three times the previously published statistics[1] we have confirmed our previous result on the splitting of the Q, and quote mass and width parameters for the split Q. In addition we have demonstrated that a consistent description of the decay characteristics requires either the presence of a $K\epsilon^0_{720}$ decay mode or an interference effect between the $K^*_{890}\pi$ and $K\rho$ decay modes, or both. If the interference effect is assumed, then SU_3 symmetry demands the presence of two Q mesons which belong to octets whose isosinglet members have $J^{PC} = 1^{++}$ and 1^{+-} respectively and which interfere with each other.[9]

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 are studying the production and decay characteristics of these known resonances in this final state in particular in regard to the predictions of the Regge-pole model. We are proceeding with the analysis of the $K\pi$ system in the reaction $K^+p \to K^+\pi^-\Delta^{++}_{1236}$. We are analyzing the data in terms of a Regge-pole model with K^* resonance production. We have also continued our study of anticascade $\bar{\Lambda}$ and $\bar{\Sigma}^0$ production in K^+p interactions at 9 GeV/c[2,5] and have added the charged $\bar{\Sigma}$ events to the sample.

K^+p INTERACTIONS AT 4.6 GeV/c

Chumin Fu, Jimmy N. MacNaughton, Gerson Goldhaber, and George H. Trilling

We are finishing the final analysis for the $K^0\pi^+p$ final state. The analysis was essentially done in August 1968.[1] To increase statistics we include our two-prong events (with K^0 not seen in the bubble chamber). We are now doing a more refined analysis.

We have been analyzing all the other final states. Particularly, we are interested in the problem of $K\pi$ scattering in the four-body final states $K^+p \to K^+\pi^-\pi^+p$ and $K^+p \to K^0\pi^0\pi^+p$.

π^+p INTERACTION AT 3.7 GeV/c

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

We have now concluded the initial measurements of all events in the 180 000 picture sample of $\pi^+p \to$ all event types. This experiment was done in the LRL 72-inch hydrogen bubble chamber. Remeasurements have been completed for about 30% of the film.

Major research activity has been centered around the following topics:

1. Strange-particle production; in particular,

$$\pi^+p \to \phi\, p\, \pi$$
$$\hookrightarrow K\bar{K}.$$

2. Detailed analysis of the state $\pi^+p \to \pi^+\pi^0p$, considering ρ, N^*, and diffraction processes.

3. A study of the detailed structure of the $\pi^+\pi^-$ mass spectrum in the final state $\Delta^{++}\pi^+\pi^-$; in particular, a search for a $\rho^0\omega$ interference in their mutual $\pi^+\pi^-$ final state. A preliminary report on the effect observed has been given to the Status Discussion Meeting on the Concept of Resonance in Subatomic Physics at the University of Oregon, The Argonne Conference on the $\pi\pi$ and $K\pi$ Interactions, and the Lund International Conference on Elementary Particles.

4. A study of the shape of the A_2 meson, which also involved detailed examination of the error structure of the kinematic fitting program. This leads to precise knowledge of resolution and is being used both to make corrections to shape functions (A_2 and in project

1. Chumin Fu, Study of the Reaction $K^+p \to K^0\pi^+p$ at 4.6 GeV/c and a Review of the Available Data, UCRL-18417, August 1968; contribution to XIVth International Conference on High-Energy Physics, Vienna, 1968.

3 above) and to extract new measurements of the ω width.

Λp SCATTERING EXPERIMENT

John A. Kadyk, George H. Trilling, Gideon Alexander, and Peter J. Gaposchkin

A second run at the Bevatron was recently completed, in which 187 000 pictures were taken with the 25-inch hydrogen bubble chamber. These are in addition to the 80 000 pictures taken in November 1968. The purpose is to obtain data on Λp interactions for Λ particles having momentum in the range 300 to 1200 MeV/c.

Due to the short Λ lifetime it is difficult to obtain a very large number of such events. In order to enhance the number of Λ particles produced, a platinum plate was installed inside the bubble chamber as a target for a K^- beam. The plate is movable and is fully retracted by an external control when coventional experiments are done in the chamber, thus avoiding shutdown periods to install or remove the plate.

From the original 80 000 pictures about 62 events have been analyzed, including 52 elastic scatter events. There appears to be one or two enhancements at certain energies, but it is too early to be certain of the significance or cause of these. Over three times as much data should be available when all the film is analyzed.

K^0_{e3} ABSOLUTE DECAY RATE; LOW-ENERGY $K^0_2 p$ AND $K^- p$ INTERACTIONS

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

Analysis is continuing on data obtained during two experiments in the 25-inch hydrogen bubble chamber: (1) K^0_2 interactions and decays at about 300 MeV/c, and (2) $K^- p$ interactions in the momentum range 150 to 320 MeV/c. From the K^- experiment, a better knowledge should be obtained of the cross section for the reaction $K^- p \rightarrow \Lambda \pi^0$. By equating this to the cross section for the reaction $K^0_2 p \rightarrow \Lambda \pi^+$ observed in the first experiment, the absolute spectrum of the K^0_2 beam can be accurately calibrated. This, in turn, will allow the absolute K^0_{e3} decay rate to be calculated from these decays observed in the same experiment. In addition, a final analysis summarizing the low-energy K^0_2 and $K^- p$ interactions will be undertaken soon.

$K^+ d$ AT 1585 MeV/c

Victor H. Seeger

In this period the data-processing phase of the experiment was completed and final analysis begun. Cross sections for the charge-exchange reaction and inelastic reactions involving a K^0 were obtained. The cross section for the final state $K^+ \pi^- pp$ was successfully obtained in spite of a rather heavy pion contamination in the beam. Other cross sections for channels involving a K^+ in the final state are being obtained now, and we are beginning the study of various angular distributions and Dalitz plots.

$K^+ D$ INTERACTIONS AT 12 GeV/c

Donald G. Coyne, Alexander Firestone, Gerson Goldhaber, John M. Hauptman, and David A. Lissauer

In April 1969 we obtained approximately 525 000 stereo exposures of $K^+ D$ interactions at 12 GeV/c. The film was taken at the SLAC 82-inch deuterium bubble chamber exposed to a 12 GeV/c rf-separated K^+ beam using the Berkeley camera system. We have begun the scanning and measuring of the film, and preliminary results indicate that the film contains approximately 850 000 $K^+ p$ interactions. We intend to restrict our attention at first to events in which there is (1) a visible K^0 decay, (2) any three-pronged event, or (3) any four-pronged event with at least one stopping track; we then have 250 000 events to measure.

Among other things, we hope to obtain data on the low-mass $K\pi\pi$ enhancement reported in 9-GeV/c K^+p interactions in which the $K\pi\pi$ system is produced coherently off a deuteron.

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10. W. R. Butler, D. G. Coyne, G. Goldhaber, B. H. Hall, J. N. MacNaughton, and G. H. Trilling, The Reaction $\pi^+p \rightarrow$ Boson + Δ^{++} at 3.7 GeV/c, UCRL-18847 Abstract, April 1969; presented at the Lund International Conference on Elementary Particles, June 25-July 1, 1969.
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12. A. Firestone, G. Alexander, G. Goldhaber, and D. Lissauer, Analysis of the Low-Mass $K\pi\pi$ Enhancement and Its Decay Modes, UCRL-18842 Abstract, April 1969; presented at the Lund International Conference on Elementary Particles, June 25-July 1, 1969.

EXPERIMENTAL PHYSICS

Chester M. Van Atta in charge

PLASMA PHYSICS

The Plasma Physics Group continues to conduct experimental and theoretical research on basic plasma and related atomic-physics problems. Good progress has been made on the study of high-frequency electric fields by their effect on emission-line shapes (two-quantum transitions). Such effects are being seen now in a hydrogen discharge immersed in a microwave cavity, as well as in a helium plasma produced by an electron beam. Work on plasma transport across magnetic fields, using a hollow-cathode discharge, is nearing completion, and the study of turbulence in a positive column in strong magnetic fields has been concluded. Use of laser-beam photon-scattering for diagnostics of a high-current sheet pinch is continuing, and the steady-state microwave-generated hydrogen plasma is beginning to yield interesting results. For instance, the latter has been used for comparison of microwave-interferometer and probe techniques for density determinations in strong magnetic fields. A new effort concerned with laser-produced plasma for injection into confinement systems has been initiated. The most recent atomic-physics studies included measurements of electron-capture cross sections for protons and deuterons in gases such as methane, magnesium mg vapor, and carbon monoxide. These matters are of interest in a number of CTR applications. Theoretical work on the quasilinear evolution of the transverse instability driven by a temperature anisotropy has been completed. Related work has been started in an attempt to derive expressions for anomalous viscosity that arises in a collisionless plasma in the presence of shear flow.

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3. K. H. Berkner, R. V. Pyle, and J. W. Stearns, Electron Capture by 0.3- to 70-keV Deuterons in Methane, UCRL-18738 Abstract, February 1969; Bull. Am. Phys. Soc. 14, 631 (1969).
4. Oscar A. Anderson and Wulf B. Kunkel, Tubular Pinch and Tearing Instability, UCRL-18415, January 1969; January 1969; submitted to Phys. Fluids.
5. Laird Warren, Transport of a Partially Ionized Plasma Across a Magnetic Field, Ph.D. thesis, UCRL-17601, September 1968.
6. Martin W. Halseth, Turbulence in the Positive Column of a Glow Discharge, Ph.D. thesis, UCRL-18678, February 1969.

25 - INCH HYDROGEN BUBBLE CHAMBER

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

The 25-inch bubble chamber has remained essentially active and capable of production throughout this report period.

GAS PURITY

The major significant down time was a period of eleven days lost when the helium-operated valves located in the chamber liquid froze in the open position. Since it required a warmup to at least 273°K to again make the valves free and operable, it is presumed that water had entered the system. Extensive testing of the gas in the helium cylinders in use and on hand did not reveal any unusual impurities. The most reasonable presumption would be that at some earlier time a helium cylinder had been used that had recently undergone the periodic hydrostatic pressure test required as a safety measure, and that the cylinder was not adequately purged after this test. The water then must have eventually migrated through the purifier used in this circuit causing the valves to freeze.

CAMERA

Of increasing concern has been the amount of repairs or maintenance necessitated by camera malfunction. Both the electronic and mechanical systems have apparently been pressed to the limit of reasonable operation. An engineering study is being made of the circuitry to consider the best methods of updating and simplification. High-speed pictures were taken of the film motion through the camera. Detailed observation of these pictures show that the film transport through the camera needs to be improved. This is particularly true in the multiple-pulse mode of operation.

A recent avalanche of static discharge on the film was overcome by the installation of new drive capstans with a conductive rubber molded on the film contact surface.

TARGET

A preliminary evaluation has been made of the possibility of installing a relatively high-speed rotating target inside the chamber. The device would operate at about 1.2°K, and this combined with the rotation presents some problems. However, the target is still considered quite feasible and worth further investigation.

DEUTERIUM

The chamber was filled with deuterium in April for an initial run for Experiment 112. A procedure has been developed and tested to use the hydrogen refrigeration compressor to accomplish the deuterium recovery. This technique not only obviates the need for a separate compressor that would be used solely for the purpose, but also speeds up the recovery process considerably. Following is a breakdown of the experiments and film production for this period:

Experiment number	Particles	Rolls	Pictures
72	π^+p	100	~ 160 000
73	K^-p	147	~ 235 200
76	K^-p (platinum target)	149	~ 238 400
87	π^+p	204	342 996
112	K^+D_2	48	~ 76 800

HEALTH PHYSICS

H. Wade Patterson in charge

CERN-LRL-RHEL SHIELDING EXPERIMENT

William S. Gilbert, Denis Keefe, Joseph B. McCaslin, H. Wade Patterson, Alan R. Smith, and Lloyd D. Stephens

One of the major efforts of the Health Physics Department has been completed. The joint 1966 CERN-LRL-RHEL shielding experiment was completed and published.[1] This department cooperated in all phases of the experimental work and write-up.

Briefly, the purpose of this experiment was the resolution of perplexing and sometimes conflicting data concerning the shielding of high-energy accelerators. More specifically, reliable data were desired for the shielding requirements of the 200-GeV accelerator in the United States and for the proposed 300-GeV European accelerator. The cost of shielding is extremely high, and refinements of theoretical calculations could reduce costly changes after construction of such accelerators. Computer programs were developed in the course of the writing which enable neutron spectra to be developed and flux-to-dose conversions to be established. The empirical model first used by Moyer was tested, and excellent agreement was obtained with the experimental data.

PRACTICAL USES OF A HIGH ENERGY THRESHOLD NEUTRON AND PROTON FLUX DETECTOR

Joseph B. McCaslin and Lloyd D. Stephens

We have assisted the Bevatron Improvement Program, resonance-extraction studies, using an extension of the system currently under development to detect and measure low levels (> 10 n/cm^2-sec) of neutrons and protons with energies greater than 600 MeV.[1]

We have used this same technique, Au $\xrightarrow{\text{spall.}}$ ^{149}Tb, as a monitor for the Los Alamos π-production experiment, currently running at the 184-inch cyclotron.

RANGES AND STOPPING POWER OF HEAVY IONS IN NONGASEOUS MEDIA

Roger Wallace

The work completed by Steward[2] and Litton[3] is being expanded in two directions. First, we are investigating more realistic beam configurations and other variables such as time and linear energy transfer as they would affect the use of heavy-ion beams in therapy and experiment. Second, we are comparing heavy-ion beams on an equal basis to their rivals in experiment and therapy-neutrons, pions, electrons, and x or gamma rays—taking into consideration geometry, linear energy transfer, depth dose, fractionation, and other properties. Some experimental work will be included, although for the most part these two projects will be theoretical.

The neutron-transport calculations for the thermal-neutron flux inside a spherical and a cubic cavity are well along, and these will

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3. Gerald M. Litton, Penetration of High-Energy Heavy Ions, with the Inclusion of Coulomb, Nuclear, and Other Stochastic Processes (Ph. D. Thesis), UCRL-17392, August 1967.

allow us to improve our understanding of the calibration of thermal-neutron detectors. The cavity will be either in water or in concrete. These results are being compared to the experimental values given in UCRL-8359.[1]

An extensive report on the properties of accelerator beams being prepared for the Task Group IIC-2 of the International Commission of Radiation Units has been almost completed. In addition five weeks of classes were conducted in Accelerator Health Physics for students sent to us from most of the major laboratories by the AEC. Work on the Manual for this course is progressing.

OPERATION HENRE

Joseph B. McCaslin, Alvin J. Miller, H. Wade Patterson, and Lloyd D. Stephens

Our participation in Operation HENRE at the Nevada Test Site has been carried out in a moderate manner. Operation HENRE ended in the late Fall 1968. Our stated experimental program for comparing distance dependence of various neutron sources (BREN, HENRE, Bevatron, 184-Inch Cyclotron) as a function of energy was designed to yield a better understanding of neutron propagation, diffusion, and attenuation in air at large distances from a source.

The measured attentuation length is about 31.5 g/cm^2 for distances from 1000 to 5000 ft. This is in excellent agreement with values for the attentuation length in concrete at 14 MeV.

Our stated objectives were completed in all major respects, and a report is being prepared.

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MEDICAL SPARK CHAMBER PROJECT

Alessandro Rindi and Harold Wollenberg

Studies continue in the application of wire spark chambers for medical purposes.[1] The investigations are directed toward a two-chamber coincidence system for position imaging. A prototype of a chamber has successfully operated in the proportional region for self-triggering of the chamber in the sparking location, thereby increasing efficiency.[2] These new chambers will replace the scintillator-triggered conventional chambers in the positron-imaging unit.

Parallel to these studies we continue the study of the direct utilization of the proportional pulses in the wire chambers for selection and localization of the ionizing pulses.

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1. L. Kaufman, V. Perez-Mendez, and H. Wollenberg, Application of Digitized Readout Spark Chamber to Clinical Uses. UCID-3184, June 25, 1968.
2. A. Rindi, J. M. Sperinde, L. Kaufman, and V. Perez-Mendez, Ionization-Triggered Wire Chambers with Magnetostrictive Readout, UCID-3271, October 28, 1968.

4. H. W. Patterson, A. de G. Low-Beer, and T. W. Sargent, Whole-Body Counting and Bioassay Determinations Made on Accelerator Workers, UCRL-18683, January 3, 1969.
5. W. S. Gilbert, D. Keefe, J. B. McCaslin, H. W. Patterson, A. R. Smith, L. D. Stephens, K. B. Shaw, G. R. Stevenson, R. H. Thomas, R. D. Fortune, and K. Goebel, 1966 CERN-LRL-RHEL Shielding Experiment at the CERN Proton Synchrotron, UCRL-17941, September 1968.

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 all the work of this organization for semiannual review.

During the period of this report (November 1968 through April 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. Research in Mathematics and Computer Science

IV. Computer Operations.

The following summarizes the work of this Group in the above areas:

I. APPLICATIONS PROGRAMMING

A. PHYSICS

For Powell-Birge Group

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

COBWEB System

Work to improve the COBWEB[1] system continues. Two scan-table teletype and a utility package have been added. The system now has 25 control points of which eight are assigned to the measuring procedure, twelve to the scanning procedure, and one control point assigns tasks to the remaining three. There are now four Franckensteins, a measuring microscope, and eight scan-table teletypes in the system.

The UTILITY package, which operates in real time with the measuring and scanning procedures, was added to the system. The executive control (or scheduler) assigns an available control point to the task requested by the user. Typical tasks include listing and duplicating decks, generating a magnetic tape from cards, printing a tape, punching cards from a tape, tape copying, dumping a tape, and stacking two tapes. These functions are performed in real time with the scanning and measuring, with no perceivable delay in response time.

1. H. C. Albrecht, E. P. Binnal, R. W. Birge, M. H. Myers, and P. Wes Weber, COBWEB: Data Reduction System, UCRL-18528, October 1968.

The COBWEB I/O package, CIO, has been written and will soon be incorporated into the system. This package will replace the IBM Interrupt System and give COBWEB greater control of I/O. This is the first step toward adding a disk to the system.

Other significant changes have been:

1. Provision for the addition of ionization hardware on the remainder of the Franckensteins
2. The capability to measure up to six fiducials
3. Expansion of the executive control point to allow assignment of parallel functions to available control points
4. Addition of a software on/off switch corresponding to hardware switches.

The CDC 6600 COBWEB editing program, COBEDIT,[1] has undergone major modifications. The most significant modifications include:

1. Format-free user input data cards
2. More flexibility in selection of output format
3. An automatic "restart" feature for runs that do not terminate normally.

We have written COBFIL, a 6600 FORTRAN program that will take a COBWEBB M44 tape and, under user direction, extract and print or make a new tape of data dependent upon sixteen parameters. COBFIL is general enough to allow additions to the parameter list so that any conceivable piece of information can be extracted from the M44 tapes, and a variety of output options may be added as the need arises.

Bookkeeping System

Routine maintenance and production running of BOOKY[2] continues. A "special studies" subroutine, SAMEVEE, has been written for use with MINNY, an abbreviated BOOKY. This routine examines large samples of events for properties such as matching production vertices and compares them with FAIR outputs to determine event "quality".

Miscellaneous

A Monte Carlo program, ORACLE, was written to determine the feasibility of experiments to measure polarization using the analyzing power of carbon in heavy-liquid bubble chambers.

A new Σ polarization program, SPOLE, was generated from the old version, DSPLAY.[1]

A 6600 program, GIOVANI, was written to convert a given n variable binary record to a set of universally acceptable Hollerith punched cards. The program reads a set of control cards declaring the logical structure of the input record. A dictionary is then created defining each word of the logical record by name and mode. An output format is then constructed to produce the Hollerith punched cards. The user is then supplied a simple FORTRAN input format statement which, when used on any computer understanding FORTRAN, converts the cards back into the original set of variables.

For Trilling-Goldhaber Group

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

Production Programs

TGIF[2] has been modified to pass more ionization information along. A method was developed to find the best section of a track to be used for ionization sampling.

Further modifications were made to the version of SIOUX,[3] which is being used to process a $\Lambda^0 p$ experiment. The lambdas

1. Physics Division Semiannual Report (hereafter abbreviated PDSR), UCRL-18235, May 1968, p. 76.
2. PDSR, UCRL-18235, May 1968, p. 75.

1. PDSR, UCRL-18235, May 1968, p.76.
2. James Miller, TGIF, Trilling-Goldhaber Physics Note 167, February 21, 1969.
3. PDSR, UCRL-18619, November 1968, p. 95.

originate from a platinum plate in the chamber, and therefore changes were made to upgrade the constraint class of certain fits. Routines were added to determine the most probable K^- beam tracks.

A new version of SIOUX is now being used for all Trilling-Goldhaber experiments. It includes a beam-editing capability that has increased the number of useful events for certain experiments. A method was added to more easily request missing masses and their errors. The spatial position of the midpoint of the ionization sampled segment of a track is now passed along in order to make corrections to the ionization at later stages.

A new version of ARROW,[1] which selects events logically on the basis of ionization information is being tested.

A new version of CHAOS[2] is now available. The I/O section was rewritten to read and (or) write packed or unpacked summary tapes. Improvements were also made to the display routines.

A bookkeeping test is being conducted using teletypes on-line to the COBWEB system. This allows the scanners to enter the indicative data for an event at the earliest possible level. This system also will eliminate data cards.

Nonproduction Programs

The Monte-Carlo program LAMP[3] has been completed. It calculates the reaction $K^+d \rightarrow \Lambda^0 p \pi^-$ as a two-stage process.[4]

1. C. A. Romascan, R. W. Casey, R. F. Tonisson, and O. I. Dahl, 6600 ARROW SYSTEM, Alvarez Programming Note P-147, August 1966.
2. Derik V. Armstrong, CHAOS, Trilling-Goldhaber Physics Note 141, December 15, 1965.
3. PDSR, UCRL-18619, November 1968, p. 96.
4. G. Alexander, B. Hall, N. Jew, G. Kalmus, and A. Kernan, Phys. Rev. Letters 22, 483 (1969).

The programs FASE 3 and KDFASE[1] were combined to enable one to fit simultaneously I = 0 and I = 1 phase shifts for K^+N. A modified program, NFASE, was written to fit the shape and normalization of the angular distributions separately. This program was used on recently received K^+p polarization data.

The programs CALC2 and VECTOR were written to calculate $\pi\pi$ scattering as a function of various reaction parameters such as mass, decay cosine, and momentum transfer.

Several minor corrections were made to PHONY,[2] and the ability to include optical distortions was added. Work has continued on the major changes that will increase the program's efficiency and allow the users to set up new experiments, change formats, and convert to other computers more easily.

The program, ELLIPSE, is used to calculate and display the results of various resonance possibilities.

For the Moyer-Helmholz Group

Ruth Hinkins and Fredric Gey

π^--^{3}He Experiment

Programming for the analysis of the π^--^{3}He cyclotron experiment nears completion.[3] Modifications of the orbit code have greatly increased the speed. New 3-parameter approximating functions for momentum and chamber position were fitted to a revised range of values. Care was taken to avoid

1. PDSR, UCRL-18619, November 1968, p. 95.
2. E. Burns and D. Drijard, PHONY (preliminary write-up), Trilling-Goldhaber Technical Note 143, March 11, 1968.
3. PDSR, UCRL-18619, November 1968, p. 96.

double values within this range. More extensive histogram output has been provided. Least-squares fitting to individual wire planes was found to be significant with this data and is being used. Changes are being made in the determination of whether several tracks are essentially the same track, and in the resolution of the ambiguous spark information into the best track before integration. Tape formats have been revised to pack more events per tape.

IBM 360 Tape Conversion

CVRT360, the package of subroutines for binary tape conversion from IBM 360 format to CDC 6600 format,[1] was completed and is available in the Computer Center Program Library.

π^0 Form Factor Experiment

Preliminary programming for this experiment has included data simulation and generation of momentum and position polynomial approximations under the assumption of a uniform magnetic field.

For the Lofgren Group

Daniel Lamb, Leo Vardas, and Donald Zurlinden

SASS Data Reduction

The DDP-24 programs, which are used for scanning the output from Bevatron Experiment 67, have been completed.[1] The reduction of data is proceeding on a daily basis. Some work will be necessary in the future to correct scanning problems that were created during the experiment.

Bevatron Experiment 82

PDP-9 programming support for this experiment includes a package of magnetic tape routines, a magnetic tape dump, and a program for testing and histogramming the scaler output. CDC 6600 programming support for this experiment is a conversion routine from 18-bit word format to a 60-bit word format.

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

A system of first-order differential equations describing particle trajectory and its perturbations has been derived. These equations reduce the number of magnetic field calculations involved in determining the initial condition vector satisfying the minimum chi-square criterion. This scheme is currently being coded for a momentum analysis program, KE2ORB, to analyze spark chamber data for Ke_2 experiment.

B. NUCLEAR CHEMISTRY

Derik Armstrong, Billie Bearden, Noel Brown, Penelope Fink, Harold Hanerfeld, Ruth Hinkins, Martin Itzkowitz, Gerald Litton, Elizabeth Quigg, Claudette Rugge, Esther Schroeder, and Leslie Wilson

Data Processing and Analysis

A nonlinear least-squares program, FELSPAR,[1] written to fit photoelectron spectra to a choice of two peak functions, plus a linear background, has been modified to allow the user to choose constraining parameters and functions and to work with individual peaks within a spectrum.

Programs TEASE,[2] CALIB,[3] MASORT,[3] CONSPIRE,[4] TAILSIG,[1] and AIRLIFT[5] were used in the processing of 9×10^6 multidimensional events. Various sorts were performed in order to analyze the data. Unexpected structure, which is thought to be due to grid effects in the sorting process, was observed in mass-interval plots per total kinetic-energy interval. Program MASORT will be changed in an effort to reduce grid effects.

Programs TE42 and TEPLOT were written to sort, tabulate, printer-plot, CalComp plot, and prepare two-dimensional distributions for

1. PDSR, UCRL-17876, November 1967, p. 54.
2. PDSR, UCRL-17876, November 1967, p. 53.
3. PDSR, UCRL-17282, November 1966, p. 29.
4. PDSR, UCRL-18619, November 1968, p. 98.
5. PDSR, UCRL-18235, May 1968, p. 80.

input to Vista fitting program SAMPO.[1] The programs were used in an experiment designed to study the angular distributions of fission fragments in coincidence with gamma rays.

The program LEIPERT, which analyzes coincidence spectra, has been written.

Two programs, MSLIB and MSCOP,[2] were modified to run on the BKY system. MSLIB creates a library of mass-spectrometer data of known compounds to provide a basis for the analysis of unknown mixtures of compounds by the second program, MSCOMP.

The programs DATA, TWO, and THREE were written to analyze data from measurements of very-low-energy cross-section reactions using position-sensitive detectors. The analysis allowed the discrimination of reaction types by the mass ratio of the two particles.

SOR16K sorts multidimensional data on magnetic tape into three fission spectra of 1024 channels each and stores them on magnetic tapes. Gamma spectra include F1-gamma heavy, F1-gamma light, F2-gamma heavy, F2-gamma light, F3-gamma heavy, and F3-gamma light (gammas in coincidence with light fission fragment 3).

GAS sorts $\gamma_1 - \gamma_2$ coincident data into spectra. The user has maximum flexibility in setting up each sort by teletype input. Descriptive information is stored with each spectrum and may be accessed with PLAY.

Using the program PLAY, spectra stored on magnetic tape or disk can be transferred into two display areas for further analysis.

1. J. F. Routti, Photopeak Method for the Computer Analysis of Gamma-Ray Spectra from Semiconductor Detectors, UCRL-17672, December 1968.
2. D. D. Tunicliff and P. A. Wadsworth, A Stepwise Regression Program for the Quantitative Interpretation of Mass Spectra, Shell Development Report No. 160-64, September 12, 1964.

Teletype-controlled operations include simple arithmetic operations, peak analysis with background fit, smoothing, compressing, and outputting on teletype, CalComp, dectape, or disk. PLAY uses chaining techniques and FORTRAN IV provided by the PDP-9 advanced software. Further development of PLAY is in progress.

Nuclear Structure

Programs GABRIEL, HELMUT, HELGAB, and BARGE were written to calculate the angular distribution of gamma rays emitted by a radioactive nucleus attached to a macromolecule in a liquid. The program STRT was written to simulate the Mossbauer spectrum expected for an axially symmetric quadrupole and collinear magnetic interactions. The program is used to get starting guesses to fit the parameters of data obtained experimentally. A new program, BASIL, has been written to calculate matrix elements of the angular part of the hyperfine Hamiltonian for an intermediate coupled wave function.

Nuclear Theory Group

The program BENT has been started to solve certain differential equations describing models of nuclear systems needed to estimate the influence of the continuum on nuclear structure. The initial step requires evaluation of some of the roots of an infinite series of equations involving Bessel functions. Since the roots are not evenly spaced and are sometimes very near an infinite discontinuity, an exhaustive tabular search method has been added to the usual interpolative methods.

The program CROSS2[1] was modified for increased speed and CalComp flexibility. Programs CROSSDP and STRIPDP were written to calculate the deuteron stripping reac-

1. PDSR, UCRL-16099, May 1965, p. 30 and PDSR, UCRL-17544, May 1967, p. 40.

tions using a macroscopic collective model. The program SCATERD was written to provide deuteron wave functions for stripping calculations. The program CROSSD was written to plot the cross section of the deuteron inelastic scattering.

A series of programs REAC, REAC PAIR, and REAC EX were written. The REAC series describes the particle transfer reaction when inelastic scattering effects are explicitly introduced. The REAC PAIR series determines higher terms neglected in the REAC series. The REAC EX series describes nucleon inelastic scattering when exchange effects (either through the Pauli exclusion principle or through the nature of the nucleon interaction) are explicitly introduced.

Computer Systems

A handler for the Nuclear Chemistry PDP-9 - 6600 data link was written. This is presently being used to help debug the link hardware. Eventually, the handler will be used to transmit data between the PDP-9 and the 6600. One of the major efforts has been devoted to making the PDP-9 data link compatible with the data link for the PDP-5 which already exists within the Berkeley 6600 hardware.

PDP-7 Hilac Operating System

A CALIBRATION subprogram was written. This routine computes energy levels of peaks as a piece-wise linear function of peak centers, using operator-specified calibration peaks and corresponding energy levels as function parameters.

A MULTI-S program is in the debugging phase. This routine will sort spectra from tape according to "windows" preset by the operator. It updates an existing program with the ability to sort several spectra in one pass.

The SYMBOLIC TAPE EDITOR was modified to accept programs from IBM-compatible tape.

PDP-9 Magnetic Tape Handler

Three device handlers were written to drive the magnetic-tape controller on the PDP-9. The first, MTZ, will handle all modes and all functions specified in the DEC advanced software system. The other two are subsets of the first.

A MACRO-9 Compatible Assembler to run on the CDC 6600 has been written and debugged.

Iron-Free Electron Spectrometer System

The ability to drive a CalComp plotter was added to the PDP-8 operating system controlling an electron spectrometer. A priority interrupt was written to improve the real time CRT display and give faster service to the various devices.

A special operating system, RAPID SCAN, was written to enable the user to perform specific types of experiments on vaporized metal sources. Documentation is being prepared.

Special Projects

A computer program TRAJ has been written to investigate the channeling of fission fragments within a crystal of uranium dioxide. The approach to this problem was proposed by Jens Lindhard[1] and used by him and others[2] for channeling light ions. The main assumption considers the potential within the channel originating uniformly from the rows containing the atoms rather than from the atoms themselves.

The major difficulty so far has been finding a suitable energy-loss relation for the heavy ions and energy range in which we are

1. Jens Lindhard, Influence of Crystal Lattice on Motion of Energetic Charged Particles, Kgl. Danske Videnskab. Selskab, Mat. Fys. Medd. 34, No. 14 (1965).
2. J. C. Poizat et al., Nucl. Instr. Methods 59, 333 (1968).

interested. A further requirement is that the energy-loss relation must be modifiable so as to take into account the effects of channeling. We are presently adapting the RECOIL program[1] for this purpose.

Program CHUBBY[2] was modified to run on the BKY system. This program uses Monte Carlo methods to trace the paths of gas molecules through a given geometrical structure with radial symmetry.

Exploratory work has been started on the problem of recognizing fission-fragment tracks etched in mica sheets. A trial program, GEM, is being written to test some of the techniques devised.

C. ACCELERATOR AND MAGNET DESIGN

Victor Brady, Bruce Burkhart, Thomas Clements, Elon Close, John Colonias, Nigel Harrison, Robert Healey, Ardith Kenney, Barbara Levine, Bobby Powell, and Steven Sackett

Magnet Design

Program TRIM[3] was converted to run under the FORTRAN Extended Compiler with a decrease of 25% in execution time. TRIM is presently used by this group to compute magnetic fields for outside contracts from Los Alamos Scientific Laboratory and LRL, Livermore.

Program LINDA,[4] a general-purpose magnet-design program, has been implemented to calculate magnets possessing axial (cylindrical) symmetry.

1. Palmer G. Steward, Stopping Power and Range for Any Nucleus in the Specific Energy Interval 0.01 to 500 MeV/amu in Any Non-Gaseous Material, (Ph. D. thesis), UCRL-18127, May 1968.
2. J. N. Chubb, A Monte Carlo Computer Programme for Analysis of Molecular Gas Flow, CLM-R54, 1966.
3. John S. Colonias, TRIM: A Magnetostatic Computer Program for the CDC 6600, UCRL-18439, August 29, 1969.
4. PDSR, UCRL-16863, May 1966, p. 31.

Program JASON[1] is used for the numerical solution of the linear Poisson equation $\nabla \cdot (\kappa \nabla \phi) = \rho$. This code, which is restricted to cylindrically symmetric or plane Cartesian problems, will handle any combination of Neumann or Dirichlet boundary conditions, as well as anisotropic nonhomogeneous media. The program is operational.

Orbit Studies

Program MAFCO III, a general orbit code for calculating single-particle trajectories in time-varying electric and magnetic fields, is under development. This calculation is fully relativistic and also computes the betatron-oscillation frequencies. A UCRL report is being written.

Program TRACE,[2] a beam transport design program, is presently operational on the CDC 6600 system. The program uses on-line facilities such as light pen and teletype. The present version is being modified to expand its capabilities and to include on-line interaction.

Program SYNCH[3] is constantly being updated to increase its instruction repertoire, as well as its computational ability. The SYNCH IBM-360 version was greatly modified to include all of the changes and additions made in the CDC 6600 version. The program is in operation both at Argonne National Laboratory and at SLAC.

Electron Ring Accelerator

Work has been done on interpreting the experimental results obtained in compression

1. S. Sackett and R. Healey, JASON– A Digital Computer Program for the Numerical Solution of the Linear Poisson Equation $\nabla (\kappa \nabla \phi) = \rho$, UCRL-18721, February 1969.
2. John S. Colonias, TRACE: An On-Line Beam Transport Design Program, UCRL-18816, January 31, 1969.
3. A. A. Garren and J. W. Eusebio, SYNCH–A Computer System for Synchrotron Design and Orbits, UCID-10153, April 10, 1965.

studies with the "Compressor III" device that is to be used to study means of extracting an electron ring from a compression chamber into an acceleration column. To achieve precise replication of current waveforms observed in the pulsed excitation of the Compressor II coils, and to permit accurate interpretation of the single-particle behavior that occurred in experiments with that unit; time-dependent coil resistance calculations were introduced into the computer programs. Existing programs were also modified and used for provisional design of extraction methods suitable for the Compressor II Device, and new, more versatile, and more accurate programs have been brought into operation for completion of this design work. The computation work has led to a design that exhibits a more suitable time variation of the focusing index for the magnetic field of Compressor III, while permitting the use of some existing coils available from Compressor II. A new program, OPERA, now permits tracing particle motion through both the compression and roll-out stages and, finally, gives an indication of the ring motion after spill-out when acceleration in the B field can act to give the ring substantial speeds in the axial direction.

Current use of this program is chiefly directed to obtaining circuit arrangements (adjustable mutual inductors) and coil configurations (trim coils) that will permit the B field to be controlled during the roll-out phase in order to avoid excessively large accelerations that would result in loss of ions from the ring. Other production programs have also been modified to permit preliminary study of compression in a static magnetic field by methods proposed at the Particle Accelerator Conference held in Washington, D. C. on March 5-7, 1969.

While these programs are presently used to calculate various arrangements and parameters of the coils, an effort is being made to control the amount of input and output so that the answers may be transmitted through telephone wires to a remotely located PDP-8 (at the site of the experiment).

Program SERA was developed to determine the currents required in a given coil geometry to produce a desired field along a given trajectory.

Special Projects

A Ph. D. thesis on generation of generalized Runge-Kutta integration methods was completed and submitted to the University of California.[1]

A spectrometer design program, TURNS, was written to compute the current needed to achieve a desired field over a given grid.

D. BIOMEDICAL APPLICATIONS

Robert Fink, Deanna Harrell, Cheryl Herrin, Ruth Hinkins, William Hogan, Mark Horovitz, Martin Itzkowitz, Myron Myers, Claudette Rugge, Marjory Simmons, Kenneth Wiley, and Edna Williams

Instrumentation

Biodynamics Data-Acquisition System

A computer based data-acquisition and analysis system has been planned for the Laboratory of Chemical Biodynamics. In collaboration with personnel from that Laboratory, we carried out a design study and selected suitable equipment. The system will include a Sigma 2 computer, disc storage, a PDP-81 computer, peripherals, and about a dozen user consoles. Users of the system will be able to initiate collection of data from instruments, control permanent storage, retrieve and display data, and specify calculations to be performed. The system will be able to

1. Elon R. Close, Generation of Generalized Runge-Kutta Integration Methods for n-th Order Systems of p-th Order Ordinary Differential Equations (Ph. D. thesis), UCRL-18650, December 11, 1968.

carry out several such tasks simultaneously.

Medical Spark-Chamber Camera

ELFIN, a new program, is being used to define objects placed between two spark chambers. Vista with teletype input is the major aid in this current investigation of possible medical applications of spark chambers.

Quantitative Models

FLY Data[1]

Genetic data in the form binary vectors from a number of experiments were processed. Output included correlation matrices, vectors of means and standard deviations, joint-occupancy matrices, distributions by number of events, mean and standard deviation of number of events, and chi-square statistics.

Recording of Film-Badge Radiation Readings

A new FORTRAN 6600 program, BADGE, is near completion. This program takes gamma and neutron radiation lifetime totals for all employees at LRL, Berkeley, and combines these totals with monthly radiation dosages read from the film badges. A master tape is updated each month, with inclusions of new employees, and a listing of the monthly, quarterly, yearly, and life-time totals of gamma and neutron radiation is given to the Health Physics Group. In addition, notification is given to this group when a employee's radiation dosage has been excessive.

Programs TPCREA and TPRET

Work has been done on a system of programs to generate statistical reports from tracer data on rats. This data existed on punched cards in a format convenient for prior programs. The data have been interpreted and placed on tape via the program TPCREA; TPRET has been coded (but not debugged) to retrieve information needed from the tape. Program options are chosen via control cards. This program provides lists, sequenced lists, sorting options, mean and standard-deviation calculation, and least-squares fits.

Program MEDFI

The medical-record storage and uptake program MEDFI[1] has been updated to accommodate variable-length data sets and internal interpretation of data.

Fast Fourier Transform Programs

The following programs were submitted to the Computer Center Library:

CFFT	Discrete, complex, three-dimensional fast Fourier transform
RFFT	Discrete, real, fast Fourier analysis and synthesis
CDC	Conversion of arbitrary length strings of display coded characters to either floating or fixed point variables.

Real Fourier analysis and synthesis programs were written for the PDP-8 and included in the NMR experiment processing program MANGLE[2] along with CRT display of both data and transforms.

Numerical experiments in physical optics using the fast Fourier transform were begun. A program TDFFT for transforming two-dimensional arrays of great size was written.

1. PDSR, UCRL-18619, November 1968, p. 102.

2. PDSR, UCRL-18619, November 1968, p. 100.

A large production run of program BRAGG[1] was set up and completed. The output of four to five hundred graphs and printout relates relative dose, relative number flux, penetration distance, and energy spectra of various ions beams, with a given energy, with respect to target elements and compounds. These results will be published in an LRL report at a later date.

A large production run of program DEDXR was set up and completed. The output of 72 graphs (216 functions) and the corresponding printout relates specific energy, stopping power, and range of various ions with respect to target elements and compounds. The results will be published in an LRL report at a later date.

Program PLOTDOG takes daily neutron and gamma dose readings from LRL monitor stations for arbitrary time spans up to one year and recalculates the readings in order to account for time differences of the readings and changes in radiation counter settings. The adjusted readings are plotted logarithmically.

Program GOTV1 uses the perspective plotting program CHTV1.[2] It displays a hyperbolic function with eight parameters on a CRT screen. The parameters and observation point are supplied via the teletype.

Program STDCRV fits a polynomial $Y = A/(BX + C)$ to data values where Y is the concentration of the solution, and X is the radiation count. The parameters A, B, and C are then used by program COUNTS to approximate unknown concentrations where the the counts are known and to graph the polynomial and data. Thirty production runs were made of these two reports.

Programs SHIRLEY and SHIR2 analyze data from glucose tolerance tests, insulin tolerance tests, and cortisone glucose tolerance tests. They calculate prescribed areas, ratios, differences, correlation coefficients, and secretion rates, and graph the data.

A flexible, general purpose CalComp plot subroutine SPLOT was written. It has been used in programs that process NMR spectra.

E. MISCELLANEOUS

Robert Belshe, Deanna Harrell, Martin Itzkowitz, David Jensen, Esther Schroeder, Marjory Simmons, and Leo Vardas

Bevatron External-Proton-Beam Control System

Version 1 of the external-proton-beam control system was completed and is now in continuous use at the Bevatron. Another set of control routines in now being added to the program to provide the ability to perturb the current in any magnet during different parts of the acceleration cycle.

Small Computer Utility Programs

Two versions of a linking loader were written for the PDP-9. The loader will load any number of programs in any order and handle all cross-referencing between them within a memory bank. A load map and list of all global symbols, defined and undefined, is printed on the teletype. Input to the loader consists of (1) a list of programs to be loaded (typed in on the teletype) and (2) paper tapes for the programs (version 1) or magnetic tapes (version 2) containing one or more programs. End-of-tape (double end-of-file) is detected and provision for reel switching is made.

1. Gerald M. Litton, Program BRAGG: A Fortran IV Program for Calculating Bragg Curves, Flux and Current Distributions, and Energy Spectra, UCRL-17391 Rev., February 5, 1968.
2. PDSR, UCRL-18619, November 1968, p. 101.

PDP-8 Assembler

The PDP-8 assembler, ASSM, has been written and modified to increase its usefulness and versatility. Modifications include increased operation code field length, multiple symbol definition, relative symbolic addressing, new pseudo operations for binary-coded decimal (BCD), and floating-point constants. The program description is available in the Computer Center Library.

PDP-8 Library System

The disc portion of a new PDP-8 Library System was written and tested. A write-up for the library system (both tape and disc) was written and is in the Computer Center Library.

Printed-Circuit Artwork

Minor debug work was done on PUZZLE,[1] a program to aid in the design of printed-circuit artwork. The main effort on this project, however, has been directed to completing the visual input procedure. INPUZ, the program to interpret light pen and teletype input and display it accordingly is successfully interpreting input for all types of components expected by PUZZLE. However, not all "erase" options are working properly. Individual connections can be deleted, but full components are not yet conveniently erased.

Inventory Control

Some minor debugging and updating have been done to STAP,[2] a program to maintain the Store's master file of inventory items. However, major effort on this project has been directed to modifying the auxiliary program A2M. A2M is a program to compare the Store's master file to that produced by the Accounting Department. Facilities have been added to correct the unit of issue and to purge the Store's master of bad catalog items presumably created by parity errors.

1. D. A. Harrell and R. Zane, Computer-Aided Design of Printed-Circuit Artwork, UCRL-18172, April 9, 1968.
2. PDSR, UCRL-16863, May 1966, p. 35.

Shop Effort Projection

SNUFL has been written in FORTRAN for the 6600 to analyze information submitted by engineers on jobs which are in the planning stage and will be coming into the Mechanical and Engineering Shops in the near future. It produces a theoretical man-hour effort projection based on the engineers estimate of the number of hours required in each shop, the job starting date, and the due date. This is in a form comparable to the shop supervisors' projections of effort required on jobs already assigned to the Shops (see SNUFL[1]).

Inorganic Materials Research Division

SHAZAM, a program to compute the average magnetic dipole absorption of a system described by an approximate spin Hamiltonian has been written. A special technique was developed to determine the approximate limits of integration. It is felt that previously used techniques have unintentionally bypassed or ignored certain regions. This new technique has proved to be considerably faster.

Theoretical Physics

A UCRL report[2] was written to summarize the numerical methods involved and the computer programs used to estimate the radiation loss that an electron ring would experience in traversing a periodic cavity structure.

Computations and Display

Three algorithms from Communications of the Association for Computing Machinery were translated into 6600 FORTRAN and tested:

a. (No. 209) Normal probabilities:
$\Phi(X) = \int_{-\infty} P(t)\,dt$.
[7 to 12 decimal-place accuracy, compared to only 6 to 8 for ERF(X); approximately 5% slower than ERF(X)].

1. PDSR, UCRL-18619, November 1968, p. 103.
2. Esther Schroeder, Numerical Studies of a Beam Loading Problem, UCRL-18792, March 1969.

b. (No. 321) student's t probabilities: $F_n(X) = 1 - \int_{-x}^{x} f_n(t)\, dt$. (Results round correctly to three decimal places for $0.2000 \leq X \geq 0.99999$.)

c. (No. 329) Occupancy numbers for distribution of n indistinguishable objects into k distinguishable slots (incorrect algorithm: corrected).

II. SYSTEMS PROGRAMMING

Eric Beals, William Benson, James Burkhard,* Jerry Borges, Douglas Brainard, Mansfield Clinnick, William Dempster, Robert Fink, Richard Friedman, Judith Glasner, Walter Hutchinson, Joyce Johnston,† Jeremy Knight,* Samuel Penny, Edward Romascan,* David Stevens, and Robert Tracy†

6411

The basic print routines were modified to provide faster printing, more convenient job separation, improved routines, and preferential treatment for short jobs. An automatic SNAPSHOT facility, which increases the reliability of the recovery procedure, was introduced. Communication procedures between the 6600's and the 6411 were modified to increase reliability.

A mechanism to allow 6411 jobs to be submitted through BRF is being designed.

Mass Storage System

The mass storage system MSS was made available for limited use by selected users to verify the (hardware and software) system and to establish operational procedures. It is expected that more general use will be permitted by mid-June. MSS recovery procedures are in an early design stage.

*Members of Group A Programming Staff.
†Employees of the Control Data Corporation.

Program Storage System

Implementation of the program storage system PSS is nearly complete, and debugging has begun. Some data-cell diagnostic features have been included, and further diagnostics are planned. The PSS interface with BRF (the expanded version of COMUT[1]) has been designed.

6600

General-purpose improvements installed in the 6600 system include:

1. disk routines designed to accomodate 6603 disk speed-up (Mod II),
2. a highly responsive dynamic priority assignment algorithm,
3. up-to-date versions of the RUN and FTN compilers,
4. the CDC standard SORT/MERGE package, accessible either via control cards or via the COBOL SORT verb.

Improvements and extensions that are in progress or planned include:

1. automatic accounting of RUSH and PRIORITY time,
2. dynamic system resident peripheral processor program library,
3. provision for a large number of control points,
4. a major reworking of all I/O routines,
5. an examination of the FORTRAN object-time mathematical routines,
6. installation of the standard CDC CP loader,
7. a mechanism to permit Chippewa-style main programs to call SCOPE-style subroutines.

A unique tape diagnostic system which provides extremely sophisticated and detailed

1. PDSR, UCRL-18235, May 1968, pp. 35 and 85.

information on tape-drive performance has been completed. It may be used to test any drive through any possible controller-channel configuration without disturbing normal operations.

A symbolic dump (SDUMP) was written for the CDC 6600. This has been extended to a disassembler (DISA). Input is a binary program in core; output is a symbolic listing. DISA consists of approximately 1000 FORTRAN statements. Versions exist for RUN and RUNF.

Terminal-Oriented Computing

COMUT was replaced with the more sophisticated BRF. Facilities for allowing submission of jobs from BRF terminals are under development. A debugging package for the experienced user has been completed; a similar package for the inexperienced user is under investigation. An output-scanning package is under investigation.

III. RESEARCH IN MATHEMATICS AND COMPUTER SCIENCE

Paul Concus, Fredric Gey, Martin Itzkowitz, 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 with a fixed angle. The solution obtained for a right circular cylinder[1,2] was utilized to provide an estimate for the film thickness remaining inside such a cylinder that is being withdrawn from a quiescent liquid. For a cylinder whose cross section contains a corner, the formulation of conditions under which a surface could not exist was completed;[1,2] experimental confirmation of these mathematical results was made indicating a possible application to the problem of describing the mechanism of water rise in trees. The case of a noncircular cylinder with smooth boundaries is being studied, and the results obtained thus far include a family of closed-form solutions and some preliminary existence criteria.

1. PDSR, UCRL-18235, May 1968.
2. Paul Concus, Static Menisci in a Vertical Right Circular Cylinder, J. Fluid Mech. 34, 481 (1968).

Theoretical Biology

A model, completed in this period, for the proliferative control of leukopoietic stem-cells predicted the following results:

Epidemiological data indict leukopoietic stress as an inducer of human leukemia: up to the age of twenty years, normal changes in leukopoietic stress are duplicated with a four-year delay by changes in the mortality from leukemia.

Evidence from Japan, the United States, and South America associates high birth rates with a high incidence of leukemia in females: in particular, the great leukopoietic stress of pregnancy in a forty year old is associated with her increased risk of death from leukemia six years later.

Spline Functions

Parametric damping of cubic spline functions was developed to eliminate extraneous inflection points that occur in the fitting of some data by the usual cubic spline function. An article was published on this development.[3]

1. PDSR, UCRL-18619, November 1968.
2. P. Concus and R. Finn, On the Behavior of a Capillary Surface in a Wedge, submitted to Proc. Nat. Acad. Sci. U. S.
3. Jonathan Young, Numerical Applications of Damped Cubic Spline Functions was published in the Logistics Rev. 4, 33 (1968).

Computer Typography

A 12-bit character representation was developed in cooperation with the Particle Data Group and will be used in all LRL applications that involve expanded-font character sets. The lowest seven bits designate one of 128 symbols (26 letters, ten digits, ten control characters, and up to 82 special characters), while the highest five bits designate shift (upper or lower case) and 15 different "fonts" (bold face, italic, Greek, superscript, etc.). The number of special characters is further increased by a factor of two, since upper and lower case can be different characters.

A new keyboard was designed which will produce 12-bit characters. This keyboard can be connected to the teletype interface of the PDP-8 (where each 12-bit character will be interpreted as a pair of eight-bit teletype characters) or to the Vista keyboard input on-line to the CDC 6600.

A program ED12 was written to display 12-bit characters on a Vista screen and to provide a simple editing capability.

The program TYPS was written to convert strings of 12-bit characters to a magnetic tape which will drive a LINOFILM photocomposer, which has 18 grids of 88 characters each. Thus, 12-bit strings generated on the special keyboards or from any other source can be used to produce high-quality printed text.

The program LINUS was written to produce proof-mode copy from the magnetic tape produced by TYPS, by generating characters for plotting on a CalComp or CRT plotter.

Studies of high-resolution plotters, including the SASS[1] optical system and Gerber plotters, were begun.

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

PDP-8/I Time-Sharing Project

A preliminary interactive system, adapted from the standard DEC disk monitor, that makes use of a Tektronix 611 Storage Scope for display of text and graphical data has been completed; it includes an editor, an interactive debugging routine, and an interactive algebraic language. Routines have been written to (1) display text at the rate of 2000 characters per second, (2) draw lines on the display at the rate of over 100 in./sec, (3) do floating-point operations in less than 200 μs each (approximately 5 to 10 times faster than DEC supplied routines), and (4) support multiple-user, time-shared operation.

Considerable thought and planning has gone into the following areas: (1) a file system, (2) reasonable swapping and time-slicing techniques, (3) line- and string-oriented editors using the storage scope, (4) an interactive algebraic language incorporating features of BASIC and Culler-Fried, (5) a multiple computer configuration, and (6) miscellaneous applications areas for an interactive graphical system of the magnitude that can be supported by this system.

Rational-Function Approximations

Rational-function approximations (using the Pade approximant method) have been shown to be a viable alternative to finite-difference methods in the solution of partial-differential initial-value problems. A paper on the subject[1] has been submitted to the ACM 1969 National Conference.

Symbolic Algebra System

The SAC-1 system for symbolic algebra on a digital computer is currently being

1. F. C. Gey and M. B. Lesser, Computer Generation of Series and Rational Function Solutions to Partial Differential Initial Value Problems, UCRL-18775, March 1969.

implemented on the 6600. SAC-1, a computer-independent version of the PM polynomial manipulation system,[1] was obtained from Professor Collins at the University of Wisconsin. The list-processing, unlimited precision-integer arithmetic, and polynomial manipulation sections have already been implemented. Only the rational-function manipulation section remains.

On-Line Data Acquisition

A paper[2] on data acquisition from CARY spectrometers, using a PDP-8/S, was presented at the DECUS Meeting held in San Francisco in December, 1968.

IV. COMPUTER OPERATIONS

Paul A. Rhodes and F. Marvin Atchley

The inactive Magnetic Tape Library consisting of over 13 000 reels was moved to the Federal Records Center in San Francisco. The storage and retrieval of these tapes is now handled by Records Center personnel.

Recertification of magnetic tapes, along with better tape-drive diagnostics and error-recovery routines has allowed us to reduce our purchase of new tapes during the past six months to about 70% of the number purchased during the preceding six months.

Since March 1969, the Operations Group has been using a new tape-drive diagnostic program, TTEST. This program enables us to make a very critical analysis of CDC 607 tape-drive performance.

The Computer Operations Group provides computing services to the Lawrence Radiation Laboratory and to outside contracts on a 24-hour day, seven day per week basis (including most holidays). During a typical day, 1100 computer programs are processed through the CDC 6600/6411 computer system requiring over 950 magnetic tapes to be mounted and producing 65 000 lines of printed output. Staffing of the computer system during times of maximum job load requires 14 persons in eight different work stations: two input control clerks, one card-reader operator, one tape librarian, one 6411 console operator, two 6600 console operators and two assistants, one CalComp-plotter operator, three printer operators, and one supervisor.

1. G. E. Collins, PM, A System for Polynomial Manipulation, Comm. A.C.M. 9, 578 (1966).
2. M. S. Itzkowitz and B. L. Tomlinson, On-Line Data Reduction from Cary 14, 15, and 60 Spectrometers, in DECUS Proceedings, UCRL-18568, December 1968.

V. PUBLICATIONS AND PAPERS

1. G. Alexander, B. H. Hall, N. Jew, G. Kalmus, and A. Kernan, Study of the Enhancement in the Λp Invariant Mass Near the ΣN Threshold in $K^- d \rightarrow \Lambda p \pi^-$ Interactions Around 1.0 GeV/c, UCRL-18695, January 1969; Phys. Rev. 22, 483 (1969).
2. R. W. Bland, G. Goldhaber, B. H. Hall, and G. H. Trilling, Search for a K^* Below $K\pi$ Threshold, Phys. Rev. Letters 21, 3 (1968).
3. W. R. Butler, D. G. Coyne, G. Goldhaber, B. H. Hall, G. H. Trilling, and J. N. MacNaughton, The Reaction $\pi^+ p \rightarrow$ Boson + Δ^{++} at 3.7 GeV/c, UCRL-18847 Abstract, April 1969; submitted to Lund International Conference on Elementary Particles, June 25-July 1, 1969, Lund, Sweden.
4. Elon Ryder Close, Generation of Generalized Runge-Kutta Integration Methods for n-th Order Systems of p-th Order Ordinary Differential Equations, Ph. D. Thesis, UCRL-18650, February 1969.
5. John S. Colonias, TRIM: A Magnetostatic Computer Program for the CDC 6600, UCRL-18439, August 1968; submitted to Nuclear Instr. and Methods.

6. John S. Colonias, TRACE: An On-Line Beam Transport Design Program, UCRL-18816, January 31, 1969.

7. Paul Concus, Heat Transfer Through a Thin Rotating Nuclear Target, Nucl. Instr. Methods 62, 199 (1968).

8. P. Concus, G. E. Crane, and H. M. Satterlee, Low-Gravity Lateral Sloshing in a Hemispherically Bottomed Cylindrical Tank, Proceedings of the 1968 Heat Transfer and Fluid Mechanics Institute, A. F. Emergy and C. A. Depew, Eds. (Stanford University Press, 1968), pp. 80-97.

9. P. Concus and R. Finn, On the Behavior of a Capillary Surface in a Wedge, to be published in Proc. Natl. Acad. Sci., U. S.

10. F. C. Gey and M. B. Lesser, Computer Generation of Series and Rational Function Solutions to Partial Differential Initial Value Problems, UCRL-18775, March 1969; accepted for the ACM 1969 National Conference, August 26-28, 1969.

11. Harold Hanerfeld, Bounds for the Roots of Certain Polynomials and Matrices, UCRL-18267 Rev., June 1968; submitted to Math. Computation.

12. M. S. Itzkowitz and B. L. Tomlinson, On-Line Data Reduction from CARY 14, 15, and 60 Spectrometers, presented at Digital Equip. Computer Users Soc. Conference, San Francisco, California, December 12-13, 1968.

13. C. M. Lederer, J. M. Hollander, and L. P. Meissner, A Computer-Based System for the Nuclear Data Compilation "Table of Isotopes", UCRL-18530, October 1968.

14. B. Levine and A. Sessler, Excitation of a Closed Cylindrical Cavity by a Charged Object Moving Along the Axis at Constant Velocity, Proc. Natl. Particle Accelerator Conference, Washington, D. C., March 1969.

15. Loren P. Meissner, High-Order Resonance for Duffing's Differential Equation, SIAM, J. Appl. Math. 17, 2 (1969).

16. S. Sackett and R. Healey, JASON—A Digital Computer Program for the Numerical Solution of the Linear Poisson Equation $\nabla \cdot (\kappa \nabla \phi) = \rho$, UCRL-18721 Rev., February 1969; submitted to Nucl. Instr. Methods.

17. Esther Schroeder, Numerical Studies of a Beam Loading Problem, UCRL-18792, March 1969.

18. Jonathan D. Young, Numercial Applications of Hyperbolic Spline Functions, The Logistics Rev. 4, No. 1917 (1968).

19. Jonathan D. Young, Numerical Applications of Damped Cubic Spline Functions, The Logistics Rev. 4, No. 2033 (1968).

20. Jonathan D. Young, Generalization of Segmented Spline Fitting of Third Order, Logistics Rev. 5, 22 (1969).

21. Jonathan D. Young, Differential Analysis of Magnetic Field Measurements with Applications, Proc. Natl. Particle Accelerator Conference, Washington, D. C., March 1969.

DATA HANDLING

Howard S. White in charge

Effort of the group was mainly devoted to two activities: the continued use of existing systems to provide measurement of bubble-chamber events in accordance with the needs of physics experiments, and the development of improved procedures and systems for measurements to be made in the future.

New development of the DAPR system for automatic analysis of bubble-chamber data was continued, as were hardware improvements associated with the Flying Spot Digitizer, including the tandem FSD. Much of the group's effort was expended in making the many small adjustments to procedures which are required to adapt the analysis systems in continued application to slowly evolving experimental data. These are discussed in more detail under the headings for each program system.

COMPUTER PROGRAM DEVELOPMENT

HAZE: Semiautomatic Event Measurement

Priscilla Davis, Wen-Sue Gee, James Greene, and Carol Osborne

The HAZE system of programs continued to operate in routine production status. New experiments were set up in the Berkeley 25-inch chamber and the SLAC 82-inch chamber. The volume of measurement declined to two thirds its earlier value, reflecting the diminished scanner manpower levels and the exhaustion of unprocessed film.

The ability to use roads generated by Franckensteins was added to the real-time program (420). This feature allows remeasurements to be made easily on the FSD, and thus provides homogenous ionization information from the FSD on events requiring remeasurements was as on events that are successful on the first pass.

FCF: Geometry, Kinematical Analysis, Data Display

Shirley Buckman, Michael Block, Donna Chrisler, Joan Franz, Dennis Hall, Vivian Morgan, Loren Shalz, and Frank Windorski

Several new experiments were set up for the 25-inch hydrogen bubble chamber. These are for the Powell-Birge 1.75-GeV/c π^+p and 1.25-GeV/c K^-p runs at the Bevatron. Processing of the Trilling-Goldhaber 12.0-GeV/c K^+d run in the 82-inch chamber at SLAC was also started. This experiment required new optics constants and a new magnetic-field subroutine.

A new version of the CLOUDY library merge program (211) was assembled and nearly debugged. The new assembly provides a more useful summary as well as a more flexible merge.

A convenient means for obtaining events of special interest was added to the FOG library merge program (136). The identification of hand-picked events is keypunched, and program 136 generates a FOG library containing only these events from the master FOG library. This results in a considerable saving of computer time as well as convenience for the user, when events of very low frequency need to be extracted for special use.

Four new developments were undertaken in collaboration with the Powell-Birge Group. The first was a study of highly curved, stopping pion tracks. The orbit calculation failed to converge for about 5% of these tracks when a proton mass was assigned. A procedure was added which detects this condition and restricts the calculation to the pion mass.

The second development was the ability to process events produced by the FAKE and PHONEY programs of Group A. Events are produced by a Monte-Carlo process allowing phase-space determinations to be made. It is hoped that this procedure will lead to a more sensitive discrimination between kinematically ambiguous final states.

The third development was the ability to accept ionization information for the COBWEB system. A new hardware feature was added to the Franckenstein which allows pulse heights to be measured. This information is passed through the various stages of FOG and CLOUDY processing and is compared to the theoretical ionization in the FAIR programs. Preliminary results from this source of ionization measurement have been extremely encouraging.

Finally, the CLOUDY system was modified to allow one vertex events to be split into two vertex events. This feature allows a more precise determination of branching ratios of very-short-lived particles to be made.

TRIST: System Monitor

Priscilla Davis and Carol Osborne

A timing problem concerning the interrupt feature of the latest version of the TRIST monitor was solved. When a FSD interrupt occurred during the time the printer was being used, the TRIST monitor was not able to return control to the real-time program quickly enough. Once this problem was solved, the new assembly of TRIST was put into production and debugging of A, B, and C levels continued.

A final assembly of the system was made to optimize storage utilization and debugging was nearly complete.

Event Accounting

Shirley Buckman and Priscilla Davis

A new vertex-calculation routine was written. This routine will be used in both the scan-level and the FOG-level production programs for event-accounting purposes. Because it is able to produce an accurate vertex point for 98% of the events, the problem of matching events from independent scans will be greatly simplified.

Program 442, which merges scan tapes and writes an Event Accounting source tape continued to operate routinely, with programming being required only to correct input data errors.

DAPR: Fully Automatic Event Scanning and Measurement

Barbara Britton, Joan Franz, Wen-Sue Gee, Dennis Hall, Laura Jontulovich, Howard White, and Frank Windorski

A detailed study of the track-following routines of the DAPR real-time program (511) was begun. The purpose of this study is to refine some of the track-following procedures. These changes will not only simplify later processing, but will also improve the quality and throughput of the final output.

Program 512E, the latest and most sophisticated version of the linking certification, and noise-deletion program, was in the advanced check-out phase. The ability to partition tracks was added. This feature is required when program 511 incorrectly follows parts of two tracks as one. Although this function is performed on a very small fraction of the tracks, it significantly improves the ability of the scanning programs to relate tracks and vertices.

Development of the vertex-finding and track-matching program (513) is essentially completed. A study of the effect of closely spaced beam tracks was made. It was found that events with no more than two beam tracks within 500 microns of the vertex were 80% successful, whereas events with more than two nearby beam tracks were only 50% successful.

However, more than half of the events in the sample were in the latter category. It would seem that significant advantages are obtained by designing experiments with well-spaced beam tracks.

The off-line quality monitor (514) was run in both B-level and C-level modes to gain operating experience and to eliminate remaining program errors. Its error-summary routines were made more comprehensive.

The CalComp display program (515) continued to operate routinely. Improvements were added to make the track labels more legible and to speed up the plotting time.

Several improvements to the Automatic Scan program (516) were added. A tally of the total number of nearby beam tracks was added to the catalog page. Two track configurations which earlier had caused fake events were guarded against. This refinement eliminated fake V^0 decays as well as nearby tracks falsely included in verticies. Finally, the ability to associate verticies connected by a charged track was added. With these improvements, the planned development of program 516 was completed.

Two important diagnostic programs were also started during this period. The first program (520) compares two HAZE libraries by computing the rms deviation of points in each track measurement on the first library with the corresponding track measurement on the second library. The program also provide a graphical display of individual point deviations along the track. In this way, track measurements by the DAPR system can be compared rapidly with measurements of the same track by the HAZE or COBWEB systems.

The second program (212) compares two CLOUDY libraries. The track momentum and the dip and azimuth angles are differenced, and the difference together with the combined errors are output in a CLOUDY library format. This program will provide checking of the final physics output for large volumes of data.

Because these comparison programs have in common the problem of associating tracks from two different measurements, an auxiliary program (522) was written which converts HAZE library tapes to DAT library tapes. In this way, both sources of measurement can be passed through the same track-numbering program (516), making the problem of track association very much simpler.

FSD HARDWARE DEVELOPMENT

Dennis Hall, Loren Shalz, and Howard White

Studies were made of the track-center detection and digitizing circuits of the existing FSD, in collaboration with Allen Arthur, Gene Binnall, and Sig Rogers of the Special Projects Group. These studies were intended to improve the performance of this FSD and to provide a basis for improved circuits in the tandem unit now under construction. Present circuits yield occasional digitizings at slightly incorrect values; these have a small effect upon ionization measurements, but a significant effect upon the effective resolution of the DAPR track-following process.

Development of new diagnostic techniques has allowed circuit improvements yielding a substantial reduction in frequency of these very bothersome false digitizings.

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 are counted separately, but the effect of any 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	830
42	72-inch hydrogen	1.5 GeV/c π^+p	Powell-Birge	1 192
46	25-inch hydrogen	1.53-1.84 GeV/c π^+p	Powell-Birge	5 545
47	25-inch hydrogen	1.53-1.84 GeV/c π^+p	Powell-Birge	1 414
50	25-inch hydrogen	1.16-1.57 GeV/c K^-	Powell-Birge	9 518
51	25-inch hydrogen	1.16-1.57 GeV/c K^-	Powell-Birge	353
52	25-inch hydrogen	1.16-1.57 GeV/c K^-	Powell-Birge	26 501
55	25-inch hydrogen	2.67 GeV/c π^+p	Powell-Birge	84
		Total COBWEB measurements processed		44 607
HAZE system				
36	72-inch hydrogen	3.3 GeV/c π^+	Powell-Birge	5 751
38	72-inch hydrogen	3.5 GeV/c π^+	Powell-Birge	26
45	25-inch hydrogen	1.5 GeV/c π^+	Powell-Birge	36 900
48	25-inch hydrogen	1.5 GeV/c π^+	Powell-Birge	197
49	25-inch hydrogen	1.3 GeV/c K^-	Powell-Birge	236
50	25-inch hydrogen	1.3 GeV/c K^-	Powell-Birge	12 694
53	25-inch hydrogen	2.7 GeV/c π^+	Powell-Birge	49 257
54	25-inch hydrogen	2.7 GeV/c π^+	Powell-Birge	15 336
71	72-inch deuterium	6.0 GeV/c p	Segrè-Chamberlain	7 407
72	80-inch deuterium (BNL)	8.0 GeV/c p	Segrè-Chamberlain	17 751
90	80-inch hydrogen (BNL)	9.0 GeV/c K^+	Trilling-Goldhaber	36 553
91	72-inch hydrogen	3.5 GeV/c π^+	Trilling-Goldhaber	22 947
		Total FSD Measurements completed		205 055
		Total events analyzed		249 662

Accelerator Operation and Development

ACCELERATOR STUDY GROUP

Edward J. Lofgren in charge

SUPERCONDUCTIVITY: JOINT LRL-NAL PROGRAM

Solenoid Transport Magnet

A superconducting end-corrected solenoid has been successfully operated in a major physics experiment at the 184-inch cyclotron. This magnet, designed and constructed at the laboratory, was maintained in a superconducting state continuously throughout the six-month experiment. It was repeatedly cycled without any difficulties. The horizontal warm-bore aperture is 4.25 in. in diameter, the length 3.5 ft, and the average field about 60 kG. The measured magnetic field before and after the six-month run was the same to one part in 4000. The entire cryostat was buried in iron and concrete shielding and was filled with liquid helium from a remote storage Dewar while the accelerator was in operation.

Dipole Transport Magnets

Several saddle-shaped-layer superconducting magnets wound with rectangular multicore NbTi conductors have been built. A 6.5-in.-i.d. magnet 3 ft long with a field of over 30 kG is scheduled to be installed in the cryostat described in the section above at the end of FY 1969.

Another design utilizes small round multicore NbTi conductor random wound directly into the cosine shaped winding required for uniform dipole field. This method of construction requires the use of intrinsically stable conductors with fine filaments of superconductor twisted about a common axis. Superconducting magnets of this type have been built and evaluated.

Systems Studies

A He refrigerator is in operation in our laboratory and operational experience has been gained in long-term operation, multiple magnets, and transfer-line losses. These data have been incorporated with previous studies on the cryogenic systems aspect of the 200-GeV experimental area.

Stability and AC Loss Studies

Studies of heat generation as a function of superconductor size, magnetic field, rate of change of magnetic field, resistivity of the normal metal substrate, and the twisting of the composite conductor have been carried out in solenoids in fields up to 60 kG and in dipoles at lower fields. Theoretical models have been developed and tested and a reasonable understanding of ac losses and flux-jump instabilities has been obtained. Improved low-loss materials make the prospects for high-current-density pulsed magnets far brighter than was the case a year ago.

Stability studies have been carried out on Nb_3Sn ribbon pancake solenoids with various thicknesses of copper interleaving. Solenoid performance could be greatly improved through this technique.

ELECTRON RING ACCELERATOR PROGRAM

Introduction

During this reporting period three principal areas of effort connected with ERA research have occupied our attention. These we refer to as Compressor 2 experiments (analysis), Compressor 3 experiments (design) and

the injector study.

Several members of the ERA group attended the Particle Accelerator Conference (IEEE) at Washington, March 5-7, and seven papers on topics connected with ERA were submitted to the Conference.

Experiments with Compressor 2

The Compressor 2 experiments at the Astron facility in Livermore terminated on November 2, 1968. The purpose of these experiments was to test the first stage of an ERA system—the formation and compression of an electron ring of high intensity.

Extensive analysis of data taken during the experimental runs at Livermore with Compressor 2 occupied several months. A satisfactory understanding of the behavior of the electron ring during compression from a major radius R = 19 cm to R = 3.5 cm was achieved. The electron kinetic energy was 3.3 MeV at injection and 18 MeV in the final, compressed state. Various pieces of data relating to the minor dimensions of the compressed ring were found to fit well together and yielded minor r.m.s. dimensions $a = 2.3 \pm 0.2$ mm radially and $b = 1.6 \pm 0.2$ mm axially. These values are consistent with the dimensions calculated on the basis of adiabatic damping. Electron density distribution was fitted very well by Gaussian form factors both radially and axially. In conjunction with the observed number of electrons $N_e = 4 \times 10^{12}$ we infer that holding fields of about 12 MV/m have been achieved. Also the focusing effect of positive hydrogen ions was established; in one observation a shift in betatron tune of $\Delta\nu = 0.14$ is observed.

The rings were observed to last for 5 to 7 msec after compression before they blew up because of magnetic-resonance effects. Their lifetime was modified by addition of gas, and the analysis of these data involves an understanding of the magnetic-field behavior during the long decay time of the field: this analysis is still continuing. The major results were reported in Phys. Rev. Letters.[1]

Of more mundane interest but of very real importance for future design was the understanding of the electrical behavior of the four coupled compressor-coil circuits, which is now fairly well understood quantitatively. This permits a detailed picture of the compression cycle, except for small uncertainties in injection conditions, eddy-current distortions, and space-charge and image-current effects. Most of the resonances that caused beam loss have been identified, but some are still uncertain.

An interesting observation during the experiments was the discovery that satisfactory and stable injection could be achieved without the application of voltage to the inflector structure. This self-trapping mechanism was not studied in any detail other than to note that it was strongly dependent on the injection current, and that at high injection currents it produced a more uniform beam than the designed inflection system. No convincing single explanation has been found, although several possible mechanism could be responsible including, for example, the effect of image forces due to the inflector structure, instabilities resulting in beam loss leading to trapping of subsequent beam, or the original Kerst mechanism for betatron trapping.

Design of Compressor 3

The aim of the Compressor 3 experiment is to test the extraction of a loaded electron ring from the compressor and to accelerate ions by collective fields to a modest but significant energy (approximately 10 MeV/proton). Although some preliminary design had taken place in Summer 1968, and extensive redesign

1. D. Keefe et al., Phys. Rev. Letters 22, 558 (1969).

effort was undertaken to incorporate the lessons learned during operation of Compressor 2.

In the light of the difficulties with resonances encountered in compressing the beam in Compressor 2, a new compressor field configuration was designed for Compressor 3. Both design and schedule planning became much clearer because of the base of experience provided by the recent Compressor 2 experiment.

Intense activity centered around the design of a coil system that will allow a compression cycle such that (a) the betatron frequency is convenient for multiturn radial injection, (b) all dangerous resonances are avoided early when the beam is large in dimensions, and (c) all resonance crossings take place as rapidly and as late as possible. (We will inject at a value of the field index, $n = -(R/B)(dB/dR)$, close to 0.6 and end up after compression with $n \approx 0.1$). For economic reasons we have paid great attention to trying to re-use existing coils, supports, vacuum equipment, etc., of the previous experiment, without too serious a compromise of the new design.

We are considering using a small coil located inside the electron ring to vary the magnetic focusing near the peak of the compression cycle. Such a unit could be useful in stability measurements and possibly in helping to traverse rapidly the dangerous region of $\nu_R = 1$ during extraction.

The vacuum requirements are quite severe. The planned compression cycle ends with a betatron tune, ν_R, of 0.96. The ionization of gas increases ν_R because of ion focusing. In order to avoid crossing the ν_R resonance prematurely, it is desirable to make $\Delta\nu_R$ due to the ionization of gas less than 0.01. If the background gas is CO or H_2O, this requires base pressures less than or equal to 10^{-8} Torr. Since the base pressure in the Compressor 2 run was about 10^{-7} Torr, significant improvements are needed. Vacuum tests with the old Compressor 2 chamber (without probes or beam) have shown that

(1) mild (125° C) baking lowers the pressure to 7×10^{-8} Torr,

(2) liquid-nitrogen cooling of an area equal to the area of one inflector bar lowers the pressure to 5×10^{-9} Torr, and

(3) liquid-helium cooling of the same area lowers the pressure to $< 10^{-9}$ Torr.

We are planning to incorporate liquid-helium pumping in Compressor 3.

Mechanically the entire apparatus will be an integral, "lathe-bed" type of structure. This method of construction is essential since the equipment must be capable of being moved in or out of the Astron injector beam rather quickly to ensure compatibility with other experiments at that facility.

Computational studies were actively pursued on the tune shifts expected for various ring intensities due to space-charge effects and various loaded ion fractions. Methods of negotiating the $\nu_R = 1$ resonance by a suitable sequence of ion loading and pulsed auxiliary fields have been studied. Computations of the stop band-widths for this and other resonances for various assumed types of misalignments of the field coils are not very encouraging, and alternative methods of extraction using image forces to stay below $\nu_R = 1$ at all times have been studied. The materials and arrangement of parts have been chosen to minimize magnetic disturbances.

Injector

A study of a new injector system for the ERA program was begun in November. It became apparent that it will be important to have such a facility in Berkeley. The interference with the Astron and other Livermore programs puts limitations on the availability of Astron

beam time to the ERA program, and the consequent scientific inflexibility and inefficiency of operating ERA experiments in Livermore would be serious disadvantages. An injector system designed for the ERA program will be smaller than the Astron accelerator, since both the pulse length and the repetition rate are much less for ERA application than those needed for Astron. The initial need is for an energy of 4 MeV and an intensity of greater than 200 A, both of which parameters should be capable of extension at a later date. If a field-emission diode can be used successfully at the initial repetition rate of 1 pulse/sec, it may deliver as much as 1000 A in the gun section (1 to 1.5 MeV). The post-acceleration section will be of the induction type, not unlike that used in the Astron injector, but will rely on ferrite rather than silicon steel cores. The shorter pulse length and lower repetition rate (compared with the Astron injector) will allow drastic simplification of the driving circuits.

An attractive feature of the development work of the induction section is that in many respects it may bear heavily on the acceleration of electron rings in the later stages of the program. The physical layout of a test facility has become quite well defined in terms of the injector dimensions, shielding, utilities, and experimental space requirements.

The so-called gun section (initial 1 to 1.5 MeV) is still in the study stage. The design at present calls for a Marx generator of about 1.2 MV in conjunction with a pulse-shaping Blumlein line to produce the voltage across a field-emission diode. Both the Marx generator and Blumlein line will be immersed in oil to eliminate sparking and breakdown. This design incorporates the possibility of replacing the field-emission diode by a hot-cathode gun, if that should prove necessary or desirable.

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BEVATRON

Edward J. Lofgren in charge

SUPERCONDUCTIVITY: LRL BEVATRON PROGRAM

A circular backstop, or analyzing, magnet for Bevatron beam targetting utilizing superconducting coils has been designed. A bending strength of 1.5 MG-in. is achieved with a central field of 70 kG and a diameter of slightly over 20 in. An iron return yoke is used to reduce stray magnetic field outside the analyzing region. The entire system is contained within a 4 ft diameter, to be compared with the present 9- by 15-ft conventional magnet system. The small size of the chamber allows a considerable increase in usable solid angle.

Initial operation is scheduled for January 1970, and installation on the Bevatron experimental area floor for July 1970.

OPERATIONS

During the period covered by this report, we have put into operation some new devices and techniques that have made substantial improvements in the flexibility and compatibility of Bevatron operating modes.

The new flattop pulsing mode was reported in the previous Physics Semiannual Report[1] and in detail in the Bevatron Operations and Development Quarterly Report.[2] This new mode allowed us to operate again long (1 to 2 sec) beam spills for counter experiments. Increased pulsing-mode flexibility developed by the Bevatron motor-generator group allowed us to have flat portions of magnetic field on the rise (mezzanine), at the top (flattop), and on decreasing field (back porch). These pulsing modes gave us the potential to satisfy simultaneously a wider range of experimental requirements as to length and type of beam-spill, and energy of primary protons.

On January 27, 1969 the pulsed magnets in the external proton beam channel were put under control of a PDP-8 digital data processor.[3] The previous controls allowed us to set the external-proton-beam transport magnet current levels and slopes for only one zone of Bevatron magnet pulsing. The new PDP-8 control system provides the necessary control to adjust the external-proton-beam magnet currents to match all zones of the new Bevatron magnet pulsing modes. This, plus some additional dc offset modes that can be selected by external triggers, provides a greatly increased ability to simultaneously satisfy the various needs of a number of experiments. For example, we are now able to run a 5.3-GeV beam spill in the external-proton-beam channel on flattop which is shared by six primary experimenters and three secondary experimenters doing counter experiments plus two beam spills for the 25-inch bubble chamber. In addition we can provide, on the same Bevatron magnet pulse, a 3.0-GeV beam spill in the external-

1. Physics Semiannual Report, May through October, 1968, UCRL-18619, November 1968, p. 127.
2. K. C. Crebbin and R. Frias, Bevatron Operation and Development 59, UCRL-18864, April 1969.
3. Don M. Evans, Digital Control of Bevatron External Proton Beam Transport Magnets, UCRL-18563, February 20, 1969; presented at the National Particle Accelerator Conference, Washington, D. C., March 1969.

proton-beam channel during a back porch on the new Bevatron magnet pulsing mode. This satisfies the beam-energy requirements of the Brookhaven National Laboratory group doing Experiment 93 at the third focus of the external-proton-beam channel II.

The external-proton-beam extraction efficiency for the rapid beam ejector (RBE) spills to the 25-inch bubble chamber were about 10 to 15 percent of the circulating beam in the Bevatron. The long spills yield about 30 to 40 percent extraction efficiency. The lower yield for RBE spills was because the beam was swept across the aperture of the first extraction magnet during the beam spill. This is characteristic of the RBE spill to an inner target with a lip. The sweeping during the spill can be eliminated if the beam is deflected radially outward onto a lipless target. The currents in the two extraction magnets are different from the currents required for the long spill. This method of extraction was developed at the Bevatron in 1966,[1] but because of the magnet current differences, was not compatible with the long beam spills. Because of the interest and work on resonant extraction, no attempt was made to develop slow spill techniques to the outer-radius target. If the position of the inner-radius target and extraction magnets were moved radially inward in the Bevatron, the RBE spill extraction efficiency decreased to a few percent. Recent operation of the internal-target experiments required that the targets operate at a smaller radius in the Bevatron. To retain compatible operation, the external-proton-beam extraction system had to be moved radially inward also. It then became impossible to operate for the bubble chamber. Tests were made showing that the RBE spill efficiency to the outer radius target did not decrease as the extraction system was moved radially inward. Tests were conducted, therefore, to determine the time required to pulse the extraction magnets to the new current levels (about 200 A difference). The time was about 60 ms. A control chassis was built to provide the proper program to the extraction-magnet currents. This system was put into operation in January 1969. The higher extraction efficiency (30 to 50 percent) plus the freedom to adjust the radial position of the extraction system provided considerable increase in flexibility in setting up for simultaneous compatible operation for a number of experiments.

From November 1968 to April 1969, we have provided beam to 19 primary experiments and eight secondary experiments. Six primary experiments were completed during this period. Five of the experiments completed were done in the external-proton-beam facility, and one in a secondary beam from an internal target. Of the 19 primary experiments run this period, four used secondary beams from internal targets in the Bevatron, and the other 15 were done in the external-proton-beam facility. Toward the end of this period, the beam intensity in the Bevatron was increased to about 4×10^{12} protons per pulse to satisfy the requirements of the experimenters. The total beam accelerated during this period was 3.4×10^{18} protons.

A new final rf amplifier tube for the synchrotron acceleration system was placed in service in January after several periods of prior operational tests. The new final amplifier uses an Eimac 4CW100,000D and replaces a system using an obsolete and unavailable tube (RCA2332). We were operating with the third and final RCA2332 tube. These three tubes were all part of the original rf system for the Bevatron.

Bevatron development for this period consisted of a number of continuing projects.

1. Robert W. Brokloff and Kenneth C. Crebbin, Bevatron Operation and Development 50, UCRL-17223, November 17, 1966.

Computer control of the external-proton-beam magnets, motor generator pulsing modes and extraction-efficiency studies have been previously mentioned. Work continues on these projects as well as continuing effort on resonant extraction of the proton-beam high-intensity studies, and a variety of minor efforts on beam diagnostics, beam sharing, and beam spill techniques.

There were three scheduled shutdown during the period covered by this report. We were shutdown for 48 hours from 8:00 a.m. on November 28 until 8:00 a.m. on November 30 for the Thanksgiving holidays. On December 20 the Laboratory was closed for the Christmas holidays and for two days of enforced vacation. Laboratory operations resumed on December 30, but the Bevatron remained shut down until January 12, 1969. During this period, routine maintenance and inspection were done on the main motor generator, the Bevatron, and on associated equipment. The Bevatron was shut down from April 7 to April 14 for routine maintenance and inspection and as part of the high-energy physics program slowdown brought about by the budget tightening.

A Bevatron Experimenter Meeting was held on January 18, 1969. It was attended by 108 persons, 73 from Lawrence Radiation Laboratory and 35 from outside institutions. Three papers were presented on current topics of interest in experimental and theoretical physics. There were reports on Bevatron operation and future Bevatron improvements. Two papers were presented on advanced accelerator studies: (1) Accelerator magnets using superconductivity, and (2) A status report on the Electron Ring Accelerator.

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184-INCH CYCLOTRON

James T. Vale in charge

OPERATION

The 184-inch cyclotron was used for research experiments approximately 94.5% of the time that the operating crew was on duty. The principal outage in this period was for replacing gaskets in the external beam system adjacent to the vacuum tank. The gaskets in this location are subject to high radiation fields and consequently to radiation damage. The cyclotron was shut down for a few days during the Christmas - New Year week, and advantage was taken of this cooling-down period to replace all gaskets in this area. The cooling-down period is necessary to minimize radiation exposure to personnel.

During this period four major experiments were concluded:

1. nn triple scattering; Surko (Lofgren)
2. $\pi^- He^3$ interactions; Sperinde (Moyer-Helmholz)
3. neutron counter calibrations; Nefkins (Haddock-Crowe)
4. continued radiological treatment of patients; (John Lawrence).

Setups for experiments include:

1. radiative capture of π^- in nuclei; Parsons (Crowe)
2. muon capture gamma rays; Kaplan (Moyer-Helmholz)
3. biomed effects of π^-; Raju (Richman)
4. pion production; Nagle et al., Los Alamos.

IMPROVED SECOND DEE

The rf design parameters for an improved second dee are being studied by Leal Kanstein and Robert Sorensen. A report by them is included elsewhere in this report. Mechanical engineering for this project is concurrently underway.

DOUBLE-DUAL dc SCR POWER SUPPLIES

Four double-dual dc power supplies were received. These supplies were designed specifically for powering the quadrupole magnets, which are high-current, low-voltage devices. However, the four units in each supply can be operated either in parallel, series, or series-parallel to make them extremely versatile.

EXTERNAL-BEAM-CAVE DOOR

A door for use in the external beam cave was constructed and put into operation. The primary purpose is to provide personnel access into this area. The design requirements were: (1) when closed, provide radiation shielding equal to that of other parts of the wall; (2) when open, occupy a minimum of floor space; (3) portable in the sense that it can be installed anywhere in the wall during setups.

NEW AIR SUPPLY SYSTEM

Many pieces of equipment located adjacent to the vacuum tank are pneumatic devices which get their source of power from the main Laboratory compressed-air system. This air supply is subject to contaminants, such as water. These cause malfunctions in the operation of the equipment, and since they are located near the accelerating tank, they are

radioactive and thus difficult to service. A small air compressor completely isolated from the main system has been installed for the operation of these devices. Since the air compressor is small and isolated, it should be possible to keep the air supply clean to prevent costly malfunctions.

NEW SECOND DEE SYSTEM

Leal Kanstein and Robert Sorensen

The cyclotron has a "C" electrode to capture and slowly spill the circulating beam. This increases the duty cycle to 75%, compared to 1% without its use. With the maximum available rf voltage of 4 kV on the "C" electrode, about 65% of the external beam and about 60% of the beam hitting an internal target can be captured. Less than 10% of the beam is lost due to gas scattering during the spilling time.

A new "C" electrode system to capture the entire beam is being designed with the following criteria:

(a) 20-kV rf voltage

(b) a frequency sweep of 0.6 MHz anywhere between 20.2 MHz and 19.0 MHz on the proton range

(c) a frequency sweep of 0.3 MHz anywhere between 14.2 MHz and 13.75 MHz on the deuteron and alpha range.

In the present system we require 10 kW of power to get 4 kV on the "C". If the same system were used to attain 20 kV, the power required would be 250 kW. This value is so large that other ways are being studied and measured on a full scale rf model.

A system as proposed by K. R. MacKenzie[1] is being modeled and some measurements have been made. From these it appears that the paper is correct and the power requirements will be nearer 100 kW than the 250 kW for a scaled system. This system and others are to be more fully investigated before the final system is designed and built.

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Permuted Keyword Index

The following pages are an alphabetical permuted index of the material in this report. Authors' names are included. All significant words are indexed; insignificant words have been automatically rejected by the computer. In some cases, the titles have been edited slightly to ensure proper word combination during automatic indexing and to provide maximum meaningful information.

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